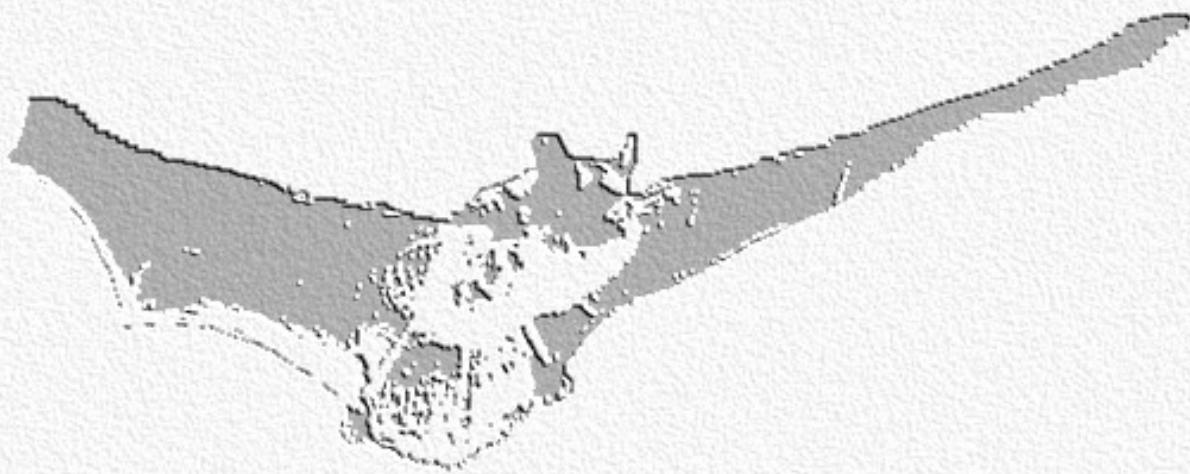


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Fringed Myotis (*Myotis thysanodes*): A Technical Conservation Assessment

**Prepared for the USDA Forest Service,
Rocky Mountain Region,
Species Conservation Project**



October 29, 2004

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COVER PHOTO CREDIT

Fringed Myotis (*Myotis thysanodes*). Cover art by Doug Keinath based on original photograph courtesy of Merlin D. Tuttle, Bat Conservation International.

SUMMARY OF KEY COMPONENTS FOR CONSERVATION OF FRINGED MYOTIS

Myotis thysanodes (fringed myotis) is recognized by several federal and state agencies as a sensitive species that is apparently rare and at risk, based on scant knowledge of local, regional, and national populations. Possible declines are likely due to a combination of primary threats including roost loss and modification, habitat alteration, and toxic chemicals. Summarized below are the main issues associated with these primary threats.

- ❖ **Roost loss and modification:** *Myotis thysanodes*, like many bat species, is very sensitive to disturbance at or modification of roosts and the surrounding environment. The most important roosts are maternity colonies and hibernacula. Disturbance of roosts (i.e., caves, mines, cliffs, buildings, snags; see Roost section) can take the form of direct human contact or alteration of the roost environment. Roost destruction has been caused by anthropogenic activities including removal of large-diameter, cavity-forming trees suitable for roosting and modification of the forest structure around roost sites. Other important impacts include human activity in caves, closure of mines without consideration of bat access, and uninformed building and bridge modification.
- ❖ **Habitat alteration:** *Myotis thysanodes* is more vulnerable to alteration of mature forest ecosystems than most bat species because: 1) it depends on old-growth conditions with abundant, large roosting snags; 2) it is a rare species; 3) it occurs in a restricted elevation zone; 4) it exhibits strong site fidelity; 5) it is sensitive to roost disturbance; 6) it has restrictive hibernation requirements; and 7) it has a low reproductive capacity. Therefore, policies and logging practices that permit intensive logging of old growth and selective removal of dead and dying trees (e.g., Healthy Forest Initiative) are likely to be detrimental to the maintenance of a landscape suitable for the persistence of *M. thysanodes*. In addition to the reduction of old-growth forest and snag density, alteration of water flow or persistence can impact bat distributions. Changes in vegetation composition or structure can alter the abundance and diversity of their insect prey base. Management actions or disturbances that serve to homogenize the landscape at the scale of typical bat foraging areas can lead to a reduction in suitable habitat.
- ❖ **Toxic chemicals:** Pesticides and toxic impoundments from industry and resource extraction can cause direct bat mortality, adversely affect reproduction, and reduce the insect prey base.

In order to be effective, conservation action must simultaneously address a combination of issues that together will determine species persistence. It is important to delineate local populations and insure persistence of the species on the landscape by implementing several practices, which are discussed in this assessment and briefly highlighted below.

- ❖ **Roost protection:** Key life history stages, most notably breeding and hibernating females, should be protected from disturbance at or near roosting sites. Roosts should be protected from alteration and visitation, and modification of the habitat around them should be kept to a minimum. Bat surveys should be conducted, and buffer zones created around known *Myotis thysanodes* roosts.
- ❖ **Habitat management:** Well-distributed, suitable roost structures should be maintained across landscapes with known *Myotis thysanodes* presence. Suitable tree roosting habitat consists of largely late-successional pine with high densities of snags in early to medium stages of decay. Suitable snag densities are likely over 8 large snags per acre, though regular pockets with several times that density may be required. This is far higher than current guidelines established for cavity nesting birds. Further, since *M. thysanodes* roosts seem to occur in less-dense microsites within otherwise contiguous mature forest, snags left in clearcuts will not provide habitat for bats as it does for some cavity nesting birds. Therefore, snag retention policies need to leave intact forest buffers around all possible roost sites and, moreover, maintain blocks of contiguous old-growth with requisite snag characteristics to maintain effective roosting complexes. Persistence of tree roosts necessitates leaving enough green trees as recruitment to maintain essential future snag densities.
- ❖ **Landscape management:** The necessary habitat mosaic must be present for persistence of populations. Ideal sites have roost structures (e.g., maternity caves, warm cliffs, and/or moderately decayed snags)

immediately proximate to water bodies (e.g., streams, lakes, beaver ponds) in a heterogeneous mix of native late-successional conifer and shrub vegetation communities (ponderosa pine or Douglas-fir intermixed with meadows, pinyon-juniper, and/or sagebrush). It appears that this mix should occur within roughly 4 km of roosts, and the scale of habitat patches should be such that all features can coexist within roughly 40 hectares.

- ❖ **Reduction of chemical exposure:** Exposure to potentially detrimental chemicals must be eliminated. Toxic surface impoundments and wetlands with contaminated sediments should be eliminated, remediated, netted, or otherwise restricted to prevent bat use. Pesticide use should be minimized and targeted to reduce spray block size, non-target insect mortality, and the potential for direct exposure of bats.
- ❖ **Population monitoring:** Bat populations should be monitored to estimate trends and thus to determine the status of local populations and the impact of management actions. Without monitoring, it is impossible to determine the true status of *Myotis thysanodes* in Region 2 forests, and it is equally impossible to determine the effects of conservation actions. Suggestions are given in this assessment, but monitoring bat populations is notoriously difficult and requires specialized expertise, so research and/or the consultation of experts is required.

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INTRODUCTION

Goal

This conservation assessment of *Myotis thysanodes* (fringed myotis) was prepared in support of the Species Conservation Project by the USDA Forest Service (USFS), Rocky Mountain Region (Region 2). It addresses the biology, ecology, status, conservation, and management of *M. thysanodes* throughout its current range, with particular attention given to the subtaxa and populations in Region 2. Our goal is to provide a summary of published information and expert interpretation of this information that can be used by the USFS to develop conservation strategies and management plans. *Myotis thysanodes* was selected for assessment because of its status as a sensitive species in Region 2 due to its rarity and potential sensitivity to disturbance.

Scope, Uncertainty, and Limitations

Although some research has been conducted on *Myotis thysanodes*, relatively little is known about most populations, particularly those in Region 2. Therefore, this assessment summarizes information from throughout its North American range and, where possible, attempts to relate this specifically to aspects of Region 2. Information was obtained from peer-reviewed literature, agency reports, and acknowledged bat experts.

There is uncertainty in all scientific inquiries, and the data described in this assessment are no exception. Herein, the strength of evidence from research is noted, and alternative explanations of observational data and expert inference are provided when appropriate. Peer-reviewed literature represents the strongest set of data and is therefore used preferentially to draw conclusions regarding *Myotis thysanodes*. Hypotheses and inferences are noted with appropriate qualifications. Where possible, when there is little or no quantitative research to back up specific ideas, expert opinion was obtained independently from several sources.

As with all pieces of literature synthesized from disparate data, this assessment has some limitations. Since most data presented herein come from specific studies with restricted research areas, interpolation and extrapolation of this data must be done with caution. It appears that aspects of *Myotis thysanodes* biology, ecology, and conservation vary over the geographic extent of its range. Therefore, the information in this

assessment should not be taken as definitive of *M. thysanodes* in any particular area. Rather, it should be used as a guide to the range of biological parameters and behaviors possible for *M. thysanodes*, which can then help to direct specific investigation to clarify the status of local populations as a prelude to major management action.

Web Publication and Peer Review

To make the information in this assessment accessible more rapidly than publication as a book or report, to facilitate its use by USFS personnel, other agencies, and the public, and to make revisions more efficient, this document will be published on the USFS Region 2 World Wide Web site. A link to this publication will also be available on the Wyoming Natural Diversity Database Web site.

Assessments developed for the Species Conservation Project have been peer reviewed prior to release on the Web. Under the editorial guidance of Gary Patton (USDA Forest Service, Region 2), this report was reviewed through a process administered by the Society for Conservation Biology, employing two recognized experts on this or related taxa. Peer review was designed to improve the quality of communication and to increase the rigor of this assessment.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Federal Endangered Species Act

Neither *Myotis thysanodes* nor any subspecies or population segments thereof are currently listed or being considered for listing under the United States Endangered Species Act (ESA). However, prior to modification of the ESA process (U.S. Fish and Wildlife Service 1996), it was listed as a Category 2 Candidate Species. Category 1 species were those for which the U. S. Fish and Wildlife Service (USFWS) had sufficient information to support a proposed listing, and Category 2 species were those for which USFWS had some information indicating that the species may be in trouble but not enough to determine whether listing was appropriate. Currently, USFWS recognize as candidates for listing only species that would have been included in the former Category 1, and they no longer maintain a Category 2 list with legal status.

Forest Service

The range of *Myotis thysanodes* encompasses portions of five USFS regions: the Northern Region (Region 1), the Rocky Mountain Region (Region 2), the Southwestern Region (Region 3), the continental portion of the Pacific Southwest Region (Region 5), and the Pacific Northwest Region (Region 6). However, according to the last master list of regionally designated sensitive species (USFS unpublished data from 2000), only the Rocky Mountain Region formally designates *M. thysanodes* as a sensitive species. Until the recent revision (effective December 1, 2003) of its sensitive species policy and list (<http://www.fs.fed.us/r2/projects/scp/index.shtml>), the Rocky Mountain Region listed only the Black Hills subspecies (*M. thysanodes pahasapensis*) on its sensitive species list (USDA Forest Service 1994). Following re-evaluation as part of their Species Conservation Project, Region 2 now lists *M. thysanodes* on its sensitive species list at the full species level (<http://www.fs.fed.us/r2/projects/scp/sensitivespecies/index.shtml>).

Bureau of Land Management

The state offices of the Bureau of Land Management (BLM) in California, Colorado, Idaho, Montana, Nevada, and Wyoming list *Myotis thysanodes* on their sensitive species lists (e.g., U.S. Bureau of Land Management Wyoming 2001). As stated in the BLM Manual 6840, this designation is meant to provide protection for species with respect to BLM land management actions that is at least equivalent to the federal policy for candidate species under the ESA. This generally means that the BLM must review programs and activities to determine their potential effect on these species.

State wildlife agencies

Myotis thysanodes is recognized as a species of special management concern by several state wildlife agencies including Idaho (Species of Special Concern), Oregon (Sensitive, Vulnerable), Utah (Species of Special Concern due to Limited Distribution), California (proposed Species of Concern), and Wyoming (Native Species Status 2). It occurs on these lists largely due to low numbers and limited distribution, suspected threats to its persistence, and often an uncertainty as to the status and trends of the local populations. In Wyoming, for instance, the NSS2 rank (ranks are from NSS1 [critically imperiled] through NSS7 [stable or increasing]) is based on Wyoming Game and Fish Department estimates that *M. thysanodes* populations

in Wyoming are restricted in numbers and experiencing ongoing significant loss of habitat, although extirpation is not deemed imminent (Oakleaf et al. 2002).

In the case of Idaho and Oregon designation makes it illegal to collect, harm, or otherwise remove the species from its natural habitat (e.g., Idaho State Code Section 36-103, Oregon Administrative Rules Section 635-100-0001). By contrast, being designated as a California Species of Concern is meant to target research and conservation efforts of the California Department of Game and Fish, but carries no legal mechanism to regulate take. Similarly, Wyoming ranks are merely a way to prioritize wildlife concerns in the state, but they carry no legal, regulatory, or management weight *per se*. The effectiveness of these designations for conservation purposes is addressed below.

Natural heritage ranks

The Natural Heritage Network assigns range-wide and state-level ranks to species based on established evaluation criteria (Master et al. 2000, Keinath and Beauvais 2002a and b). *Myotis thysanodes* merits a global rank of G4-G5, which means that when the range-wide population is considered, it is deemed by Heritage scientists to be Apparently Secure. This is based on a synthesis of state ranks and biological evidence that suggests it is “widespread in western North America”, has over 100 reported occurrences in the central Natural Heritage database, has an “apparently low” abundance, and “appears to be moderately threatened” (NatureServe Explorer 2004).

Although apparently secure at the global level, at a smaller scale *Myotis thysanodes* can be quite rare and/or sensitive, and it has therefore received less secure status estimates from several states. Fifteen western states and provinces have assigned a State Rank to *M. thysanodes*, and seven of these states rank it as S2 (imperiled) or S1 (critically imperiled). In general, state ranks are assigned based on the assessed risk of extinction within a state, where S1 species are deemed critically imperiled and S5 species are deemed demonstrably secure. These assessments are based on biological information on population status, natural history, and threats at the state level. Specific State Ranks are as follows, with Region 2 states underlined: Arizona (S3-S4), California (S4), Colorado (S3), Idaho (S1?), Montana (S3), Nebraska (S1), Nevada (S2B), New Mexico (S5), Oregon (S2?), South Dakota (S2), Texas (S3), Utah (S3B), Washington (S3?), Wyoming (S1B,S1N), and British Columbia (S2-S3). A question mark (?) indicates that the rank is uncertain, generally

due to a lack of information on population status. SB and SN designations refer to breeding and non-breeding populations, respectively, and they are generally used for species whose conservation concerns vary with season (e.g., migratory animals).

Western Bat Working Group

The Western Bat Working Group (1998) ranked *Myotis thysanodes* as a species of high conservation concern in four out of 10 ecoregions in which it occurs and as moderately high priority in four others (Figure 1). Regions of high concern included the Maritime Regime Mountains, Mediterranean Division, Intermountain Semi-Desert Province, and Intermountain Semi-Desert and Desert Province; the last two of these occur in USFS Region 2. In addition, a large portion of Region 2 is encompassed by the several ecoregions for which *M. thysanodes* was listed as moderately high priority,

namely the Temperate Steppe Regime Mountains, which includes most of the Colorado Rockies, and the Temperate Steppe Division, which includes the Great Plains. The only Region 2 state working group to thus far explicitly rank its bats is Colorado, which lists *M. thysanodes* as having the second highest conservation priority of its 18 bat species (the highest priority was the Townsend's big-eared bat (*Corynorhinus townsendii*; Ellison et al. 2003).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

To date, there are no management plans or conservation strategies pertaining explicitly to *Myotis thysanodes* in any portion of its range. However, non-regulatory conservation strategies have been drafted for other bat species, such as two subspecies of Townsend's

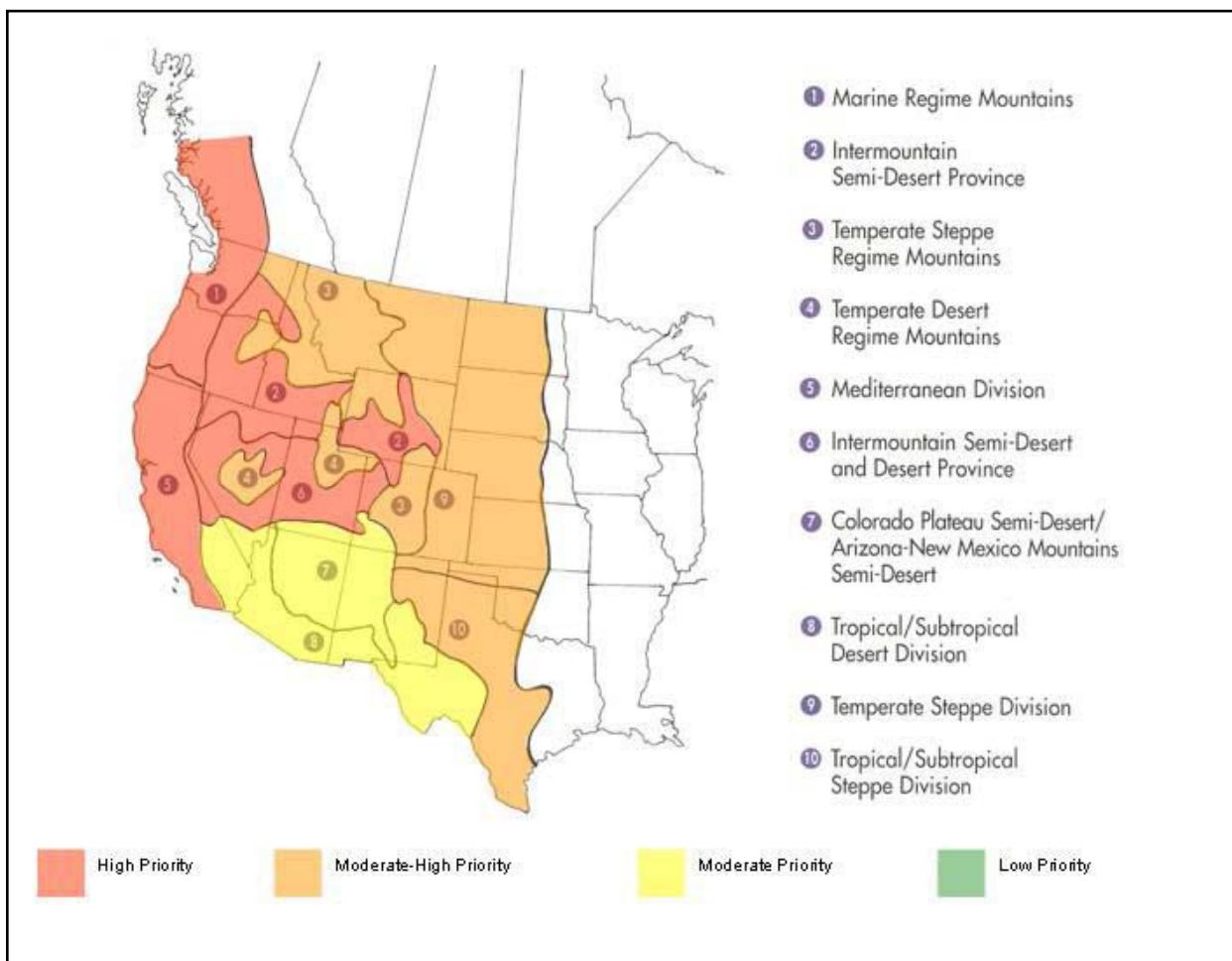


Figure 1. Regional Conservation Priority of *Myotis thysanodes* throughout its range as defined by the Western Bat Working group. Image adapted from Western Bat Working Group (1998).

big eared bat (*Corynorhinus townsendii townsendii* and *C. t. pallescens*; Pierson et al. 1999). Also, some states have recently completed or are in the process of drafting bat conservation plans designed to provide conservation guidance for the suite of bats present within their boundaries. The completed plans thus far are the Nevada Bat Conservation Plan (Altenbach et al. 2002), the Arizona Bat Conservation Strategic Plan (Hinman and Snow 2003), the Colorado Bat Conservation Plan (Ellison et al. 2004), and the South Dakota Bat Management Plan (South Dakota Bat Working Group 2004). Conservation plans for Utah, Washington, and Wyoming are under development (Grenier personal communication 2004). These plans differ greatly in their level of detail and the strength of their management recommendations, but most provide general guidance and offer recommendations pertaining to specific species relevant to their habitat use. Although portions of these plans are not pertinent to *M. thysanodes* in Region 2, they contain substantial guidance that is directly applicable and will also aid a broad range of other bat species.

Since the largest conservation concern for most bats is loss of suitable habitat, the core of all such plans is preservation of roosting structures and foraging habitat. This is generally approached on a species- and habitat-specific basis. Objectives pertinent to *Myotis thysanodes*, drawn in part from the above-noted conservation plans, have been highlighted in the management sections of this assessment. If these conservation guidelines are rigorously followed and if future information (see Information Needs section) does not uncover additional issues, then we believe adequate protection will be afforded *M. thysanodes* within Region 2. However, it should be noted that these plans are designed by independent experts (usually members of Western Bat Working Group and representatives of wildlife management agencies) and they therefore carry no legal weight. They will only be effective to the extent that they are officially adopted and implemented by land management agencies such as the USFS and BLM. Ideally, listing *M. thysanodes* as a sensitive species and incorporating such guidelines as the vehicle by which it is managed will ensure effective conservation. This will only happen if the guidelines, through agency sensitive species policies, are allowed to impact land and timber management actions and mine reclamation policies.

USFS old-growth conservation plans are another mechanism through which conservation of important habitat might be effected. Given that *Myotis thysanodes* depend on older forests with suitable roost snags and foraging habitat (see Habitat section), USFS initiatives

to conserve stand mosaics that meet those needs will likely enhance the long-term persistence of the species. This will occur only if criteria important to *M. thysanodes* are factored into the old-growth decisions and those decisions are enacted on the ground.

Many states have non-game regulations that prohibit unauthorized destruction of native, non-game wildlife. The enforcement of these regulations is often tied to state wildlife management plans, which generally contain lists of species thus afforded protection (e.g., Species of Special Concern, Sensitive Species). Several states (see above) explicitly designate *Myotis thysanodes* on these state lists. However, this protection generally takes the form of non-binding guidance on conservation needs or is limited to prohibitions of direct impact (e.g., poaching, poisoning) and does little to address the major threats to bats (e.g., roost disturbance, habitat alteration). Until state policies expand their scope to include protection of suitable habitat for bats and concurrently demonstrate a fiscally feasible and legally defensible mode of enforcing this protection, they will remain marginally effective tools for conserving *M. thysanodes*.

Finally, there are numerous other conservation mechanisms that might impact bats in general. For example, conservation strategies and best management practices are published by a variety of state, regional, and national organizations (e.g., Watershed Advisory Groups and Conservation Districts, state Departments of Agriculture, state Weed and Pest Districts, Departments of Reclamation and Environmental Quality [Abandoned Mine Land Divisions], Wildlife Services [e.g., USDA, APHIS], County Commissions, City Councils). These groups are valuable in that their actions can greatly impact bat habitat, but there are substantial problems in relying on them as primary means of bat conservation. The first basic problem is that, although they deal with resources that are valuable to bats, their primary missions do not directly involve bat conservation, and bats appear tangentially, if at all, in their planning processes. The second problem is that the products of these groups are substantially advisory in nature and usually carry no legal weight. The third problem is that most such groups plan locally and their products vary widely in focus and quality. Bat conservationists and land managers should work with these groups to help ensure that bats are considered in their planning efforts. However, this should be done in connection with approved, comprehensive bat conservation plans (as noted above), and these groups should never be relied upon as a primary means for the conservation of any bat species.

Biology and Ecology

Description and systematics

Taxonomy

Myotis thysanodes is part of a group of bats sometimes referred to as the “long-eared” *Myotis* (*M. thysanodes*, *M. auriculus*, *M. evotis*, and *M. keenii*), which appear to have a high taxonomic affinity based on morphology and chromosomal characteristics that differ from other North American vespertilionids (Bickham 1979). A similarly close affinity between “long-eared” myotis in the southwestern United States has been assigned to *M. auriculus*, *M. evotis*, *M. milleri*, and *M. thysanodes* (Reduker et al. 1983).

There are three recognized subspecies and one uncertain subspecies of *Myotis thysanodes* (Figure 2). *Myotis thysanodes thysanodes* occurs in the main part of the species’ range, *M. t. aztecus* occurs in Oaxaca, Mexico (Wilson and Ruff 1999), and *M. t. pahasapensis* occurs only in the Black Hills of South Dakota, Wyoming, and Nebraska (Bole 1935, Jones and Genoways 1967, Barbour and Davis 1969). According to Jones and Genoways (1967), *M. t. pahasapensis* has slightly larger ears (average 18.7 mm versus 16.2 mm in *M. t. thysanodes*), a shorter forearm (41.1 mm versus 43.0 mm), a smaller skull (see measurements in Jones and Genoways 1967), and darker ears and membranes that contrast in color with the dorsal pelage. While not universally recognized as a valid subspecies, *M. t. vespertinus* has been suggested

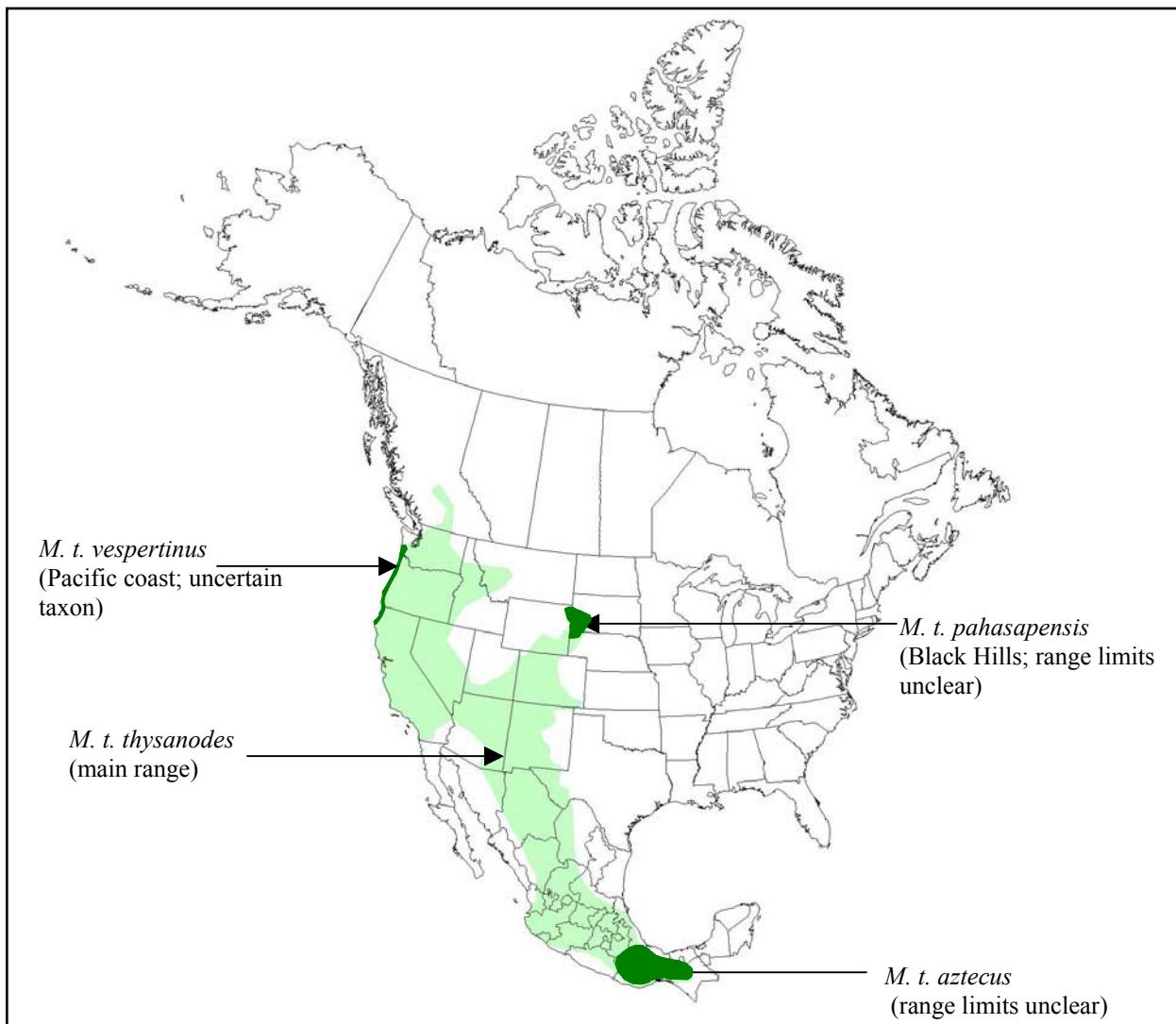


Figure 2a. North American range of *Myotis thysanodes* adapted from range maps compiled by Bat Conservation International, Austin, Texas, O’Farrell and Studier (1980), and Manning and Jones (1988). Current estimated year-round range is shaded in light green. Approximate subspecies locations are in darker green.

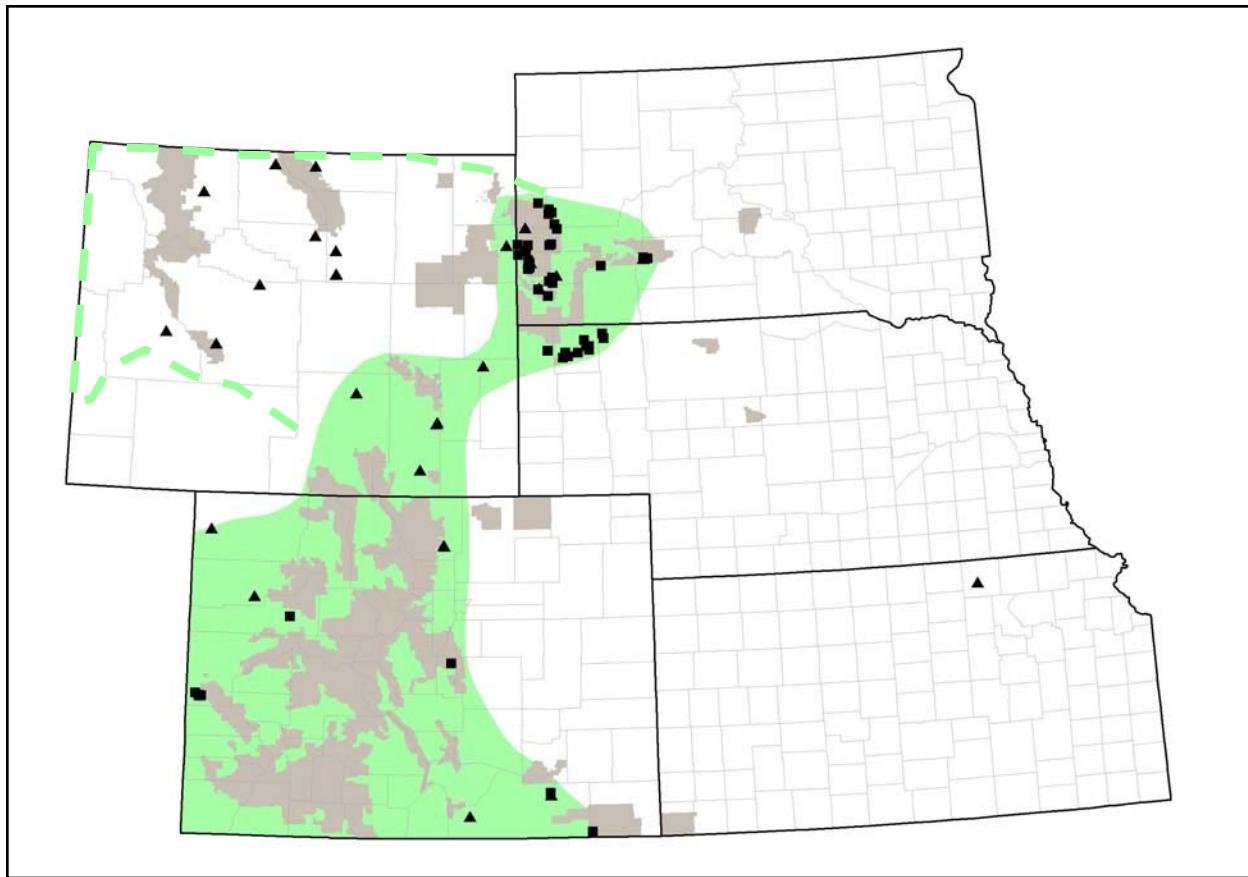


Figure 2b. Potential distribution of *Myotis thysanodes* in Region 2. Region 2 management units appear in gray. Black squares represent observations subsequent to 1990 and black triangles represent observations prior to 1990. The solid green polygon represents estimated current distribution based on observations and national distribution maps (O'Farrell and Studier 1980, Manning and Jones 1988, Bat Conservation International). Dashed green line represents the probable historic range in Region 2 based on observational records, which are mostly museum specimens.

to occur west of the Cascade Mountains, along the Pacific coast, from southwestern Washington south through Oregon and into northwestern California as far south as Humboldt and Shasta counties (Manning and Jones 1988). It is tracked separately by the Washington Natural Heritage Program.

Identification

Unlike all other *Myotis* species in North America, *M. thysanodes* has a conspicuous fringe of hair along the posterior border of the interfemoral membrane that extends 1.0 to 1.5 mm beyond the uropatagium (Figure 3; Jones and Genoways 1967). Other morphometric characteristics of *M. thysanodes* are reported in Table 1. There appears to be geographic variation in fur color, with darker animals occurring in the northern portions of the species' range (Miller and Allen 1928 in O'Farrell and Studier 1980). The dorsal fur varies in color from

yellowish brown to dark brown with olive tones (O'Farrell and Studier 1980) or reddish tones (Barbour and Davis 1969). The ventral fur is usually somewhat paler and can be touched with ochre (Barbour and Davis 1969), but there may not be much color difference between the dorsal and ventral surfaces (O'Farrell and Studier 1980). The Black Hills subspecies, *M. t. pahasapensis*, is brownish to tawny olive or ochraceous buff above and pale to light ochraceous buff below (Jones and Genoways 1967).

Bats can often be identified by the frequency modulation of their echolocation calls. The pattern of *Myotis thysanodes* echolocation calls begins with a variable downward sweep in frequency to 28 to 33 kHz in 1 to 3 milliseconds (Figure 4). Although generally having no constant frequency portions, *M. thysanodes* calls can sometimes terminate in a nearly constant frequency tail lasting 2 to 7 milliseconds.

(A)



(B)



Figure 3. Photographs of *Myotis thysanodes* showing (A) general appearance and (B) the uropatagial fringe. (© Merlin D. Tuttle, Bat Conservation International).

Table 1. Reported morphometric measurements of *Myotis thysanodes*.

Source	Forearm Length (mm)	Wing-span (mm)	Ear Length (mm) ^a	Total Length (mm)	Tail Length (mm)	Weight (g)	Pelage
Banfield 1975; Cowan and Guiguet 1956			16 to 18 (5 b.s.)	89 (86 to 93)	38.5 (36 to 41)		Pale buffy-brown; Pale sandy-brown
Boyce 1980	42.3 ^b	270 to 300	14.0 ^b long	74.1 ^b	24.9 ^b		
Christy and West 1993						5 to 7	Light brown dorsal fur, paler below with black membranes
Barbour and Davis 1969	39 to 46	265 to 300	16 to 20	91 to 96			Reddish to dark brown above, pale below
Davis 1966	43		16.5	86	35		“... full and about 9 mm long on the back.
Genter and Jurist 1995	41.4	270 to 300		89.8		41.5	Upperparts uniform warm buff, tips of 'hares shiny, bases fuscous black; underparts dull whitish.'
Jones and Genoways 1967	39.2 to 43.3		17 to 21			40 to 44	“Dorsal pelage varies from medium brown to pale buff with individual hairs being grayish plack basally, ventral pelage is paler”
Jones and Webb 1952 ^b		44 ^b			87		Buckthorn brown and tawny-olive to light ochraceous buff below
Musser and Durrant 1960 (Utah)	42.5 (41.5 to 44.5)		15 ^b				
O'Farrell and Studier 1980	40 to 47		17.4 (16 to 19)		85.6 (80 to 92)		Same as Miller and Allan 1928 but “some specimens which possess lighter, buffy-tipped hairs”
Wilson and Ruff 1999	40.3 to 45.3		16 to 20 (nose to vent)		43 to 59 (nose to vent)	34 to 45	yellowish to olive brown above, same below
				80 to 99 (total length)		35 to 45	6.0 to 11.8

^a Lengths in parentheses refer to how far, in millimeters, the ear extends beyond the snout (b.s.) when laid forward. [make sure this is extracted from all the references in this table]

^b Measurement by Boyce (1968) were taken from a dried study skin (Specimen Number UW2269). Measurements of ear and forearm by Jones and Webb (1952) were also from a study skin. Ear measurements from study skins are likely to be too small, due to shrinkage during the drying process.

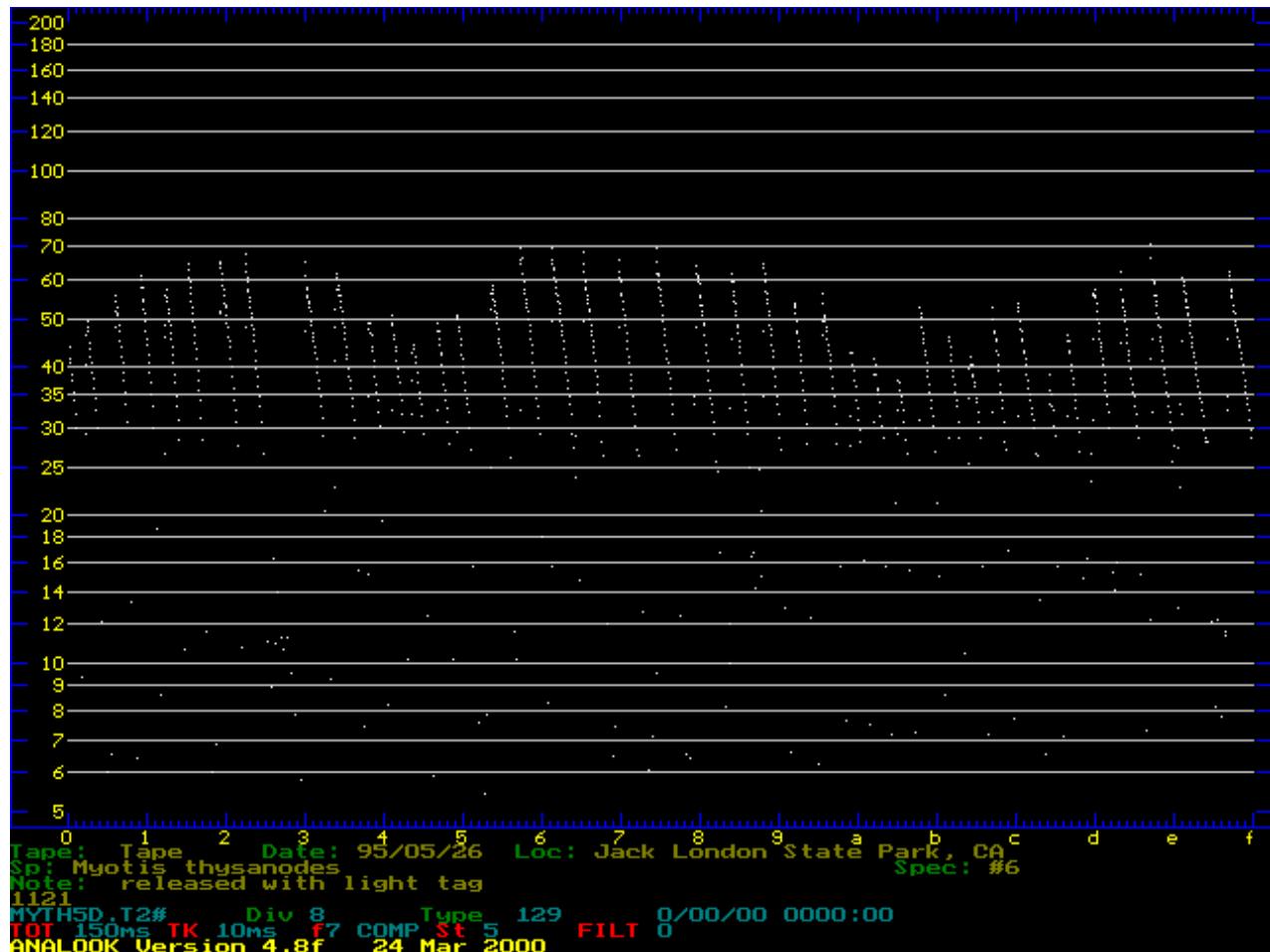


Figure 4. Example of a *Myotis thysanodes* echolocation call from California, recorded and displayed via Anabat[©] and Analook[©]. The vertical axis is frequency in kHz. Note the broad frequency sweep of the calls (~ 70 kHz [sometimes more than 100 kHz] to less than 30 kHz) and the rapid downward sweep between these frequencies, with no constant frequency tail. This combination of features is typical of *M. thysanodes*, but other bats (e.g., *M. evotis*, *M. volans*) can have similar calls under certain circumstances.

Although not diagnostic, the wing and tail membranes of *Myotis thysanodes* are thick and puncture-resistant compared to many other bat species, presumably to mitigate injury while gleaning insects on the ground or in thorny vegetation (O'Farrell and Studier 1980, Wilson and Ruff 1999). The aspect ratio (wing span²/wing area \cong 6) is low, which is typical of slow, highly maneuverable bats that forage by gleaning (O'Farrell and Studier 1980).

The sexes are generally distinguished based on external genitalia. In the non-breeding season, sexual differentiation is more difficult. Females tend to have slightly, but significantly, larger heads, bodies, and forearms (Williams and Findley 1979 in O'Farrell and Studier 1980). The baculum of *Myotis thysanodes*

was described as 0.77 mm long and dumbbell shaped with a ventral groove (Vaughan 1955 in O'Farrell and Studier 1980).

Myotis thysanodes pahasapensis has been confused with *M. evotis* where they co-occur. They can be distinguished based on external characteristics, most notably the conspicuous uropatagial fringe. Also, *M. t. pahasapensis* has smaller ears (average 18.7 mm versus 20 mm) and longer forearms (average 41.1 mm versus 38.6 mm). In other areas, *M. evotis* has either no or a poorly developed uropatagial fringe and longer ears can be evidenced by the fact that the ratio of ear length to forearm length is greater than 0.5 (unlike *M. thysanodes*) (Genter and Jurist 1995).

Distribution and abundance

Range

Myotis thysanodes is predominantly found in western North America, occurring from southern British Columbia, Canada (where it is only known from a few specimens), south through southern Mexico (**Figure 2**; Jones and Choate 1978, O'Farrell and Studier 1980, Hall 1981, Rasheed et al. 1995). It occurs west to the Pacific coast and east to the Rocky Mountains of Region 2 (**Figure 2**), with a potentially isolated population in the Black Hills of South Dakota, Wyoming, and Nebraska. Populations in Mexico are predominantly found in the central highlands. Occurrences have been documented in 14 states (Arizona, California, Colorado, Idaho, Nebraska, New Mexico, Montana, Nevada, Oregon, South Dakota, Texas, Utah, Washington, Wyoming).

Myotis thysanodes thysanodes occurs over most of Region 2, and the Black Hills subspecies (*M. t. pahasapensis*) is restricted to the Black Hills of South Dakota and Wyoming and extreme northwestern Nebraska, all within Region 2. Questionable records exist farther east (Czaplewski et al. 1979). Two subspecies (*M. t. aztecus* and *M. t. vespertinus*) do not occur in Region 2.

Myotis thysanodes distribution does not appear to be substantially impacted by major topographic features, as evidenced by a study on the Unita Mountains of Utah and Wyoming. Unlike many species whose range was partially defined by this east-west mountain range, *M. thysanodes* occurred throughout the region with minimal geographic variation (Kirkland 1981).

Abundance

Based on information compiled from published sources (**Table 2**), it appears that although relatively rare, *Myotis thysanodes* can be locally abundant. Even in habitats where it would be expected (see Habitat section), this species usually represents a small fraction of bats detected in survey efforts, averaging $\sim 7.5 \pm 2.3$ percent of bats identified (range: 1.3 to 22.8 percent; **Table 2**). The high end of this range was an outlier that occurred in northern Arizona, where *M. thysanodes* was nearly twice as abundant as documented in any other study (Herder 1998). Without this outlier, the mean frequency of occurrence decreases to $\sim 6.3 \pm 2.3$ percent of identified bats (range: 1.3 – 13.7 percent); the highest densities appear to be in the Black Hills of South Dakota and in northern Arizona (Czaplewski et al. 1979, Herder 1998). In one Black Hills study, *M.*

thysanodes represented 13.7 percent of 1,699 mist net captures over 4 years (Cryan 1997); only *M. volans* and *Eptesicus fuscus* were more abundant. *Myotis thysanodes* accounted for only 7 percent of 405 mist net captures for a study in Badlands National Park, South Dakota, ranking 4th in relative abundance among the nine species captured (Bogan et al. 1996). Similarly, *M. thysanodes* was the 4th most captured species during bat surveys of Jewel Cave National Monument, South Dakota (35 captured out of 587 total, or 6 percent of captures), and a few individuals were documented hibernating in the cave during several winters (Choate and Anderson 1997).

The above information, summarized from **Table 2**, is provided to give a rough idea of how often *Myotis thysanodes* is captured and thus how abundant it may be relative to other bats. These numbers should be viewed with extreme caution given the difficulties in conducting bat surveys (see Survey, inventory and monitoring section). For example, *M. thysanodes* routinely forage above typical mist net levels (O'Farrell and Studier 1980; see Habitat and Foraging sections), so only those ponds to which they come to drink may result in representative capture rates. Conversely, if such a pond happened to be located near a large roost, *M. thysanodes* could be over-represented in the captures, and its local abundance could be over-estimated. Similarly, if one study happened to place nets at a wetland near a major travel corridor (e.g., a forest edge at the base of a roosting cliff), *M. thysanodes* may be more likely to be caught than in a similar study that happened not to find such an ideal netting location. Factors like these cannot be gleaned from published literature but must be considered as possible reasons for the capture variances observed. However, since the above numbers provide our only estimate of *M. thysanodes* abundance, which appears relatively replicable over the suite of studies presented, we believe that it is valuable information that Region 2 biologists can use to roughly judge their own abundance estimates.

Population trend

To our knowledge, no monitoring efforts have targeted *Myotis thysanodes* on a local or regional scale, much less rangewide, so no statistically valid trend data are available. Anecdotal evidence suggests increases in some areas and decreases in others, possibly confounded by short-term fluctuations. The range in Wyoming may have contracted over the last 50 years. Population trends are discussed more thoroughly in the trends portions of the Biological Conservation Status section.

Table 2. Selected occurrence reports of *Myotis thysanodes* across its range. This table reports only the results of surveys that identified *M. thysanodes*, so it reflects relative abundance in currently occupied habitat. There have been many other surveys within *M. thysanodes* range that have not reported individuals of this species.

MYTH Encounters									
Source	M/F	Percent of Total	Hourly Rate ^b	Species Identified	Rank ^a	Location	Collection Dates	Elevation (m)	Habitat
Agyagos et al. 1994	28/7	6	3.7 ^b	18	10	Tonto Rim, Central Arizona	1993	1,200 to 1,900	Ponderosa pine, pinyon-juniper, mixed conifer
Bogan et al. 1996	24/5	7	nr	9	4	Badlands National Park, South Dakota	1992, 1993	nr	Cottonwood and cedar
Choate and Anderson 1997	35	6.0	nr	~8	4	Jewel Cave South Dakota	1989	1,580 to 1,664	Clearings bordered by ponderosa pine
Cockrum et al. 1996	379/786	9	21	5	Mohave County, Arizona	1959, 1964	nr	Oak and pine forests	
Cryan 1997	202/30	13.7	nr	10	3	Southeastern South Dakota	nr	1,037 to 1,768	Unspecified, probably ponderosa pine
Ellinwood 1978	3	1.3	nr	14	10	Southeastern Colorado	1977 to 1978	1,097 to 2,934	Pinyon-juniper near cliffs and canyons
Fenton et al. 1980	6	1.4	nr	11	8	Southern British Columbia	1979	<700	nr
Herder 1998	67/75	12.3	nr	17	3	Northern Arizona	1996 to 1997	2,100	Ponderosa pine and pinyon-juniper
Herder and Jackson 1999	75	22.8	0.5 -2.2 ^c	13	2	Northern Arizona	1998	1,600 to 2,100	Ponderosa pine and pinyon-juniper
Morrell et al. 1999	49/52	9	8.7 ^c	11	5	Coconino National Forest, Arizona	1993 to 1995	2,000 to 2,500	Ponderosa pine
Morrell et al. 1999	8/13	3.8	1.2 ^c	15	7	Coconino National Forest, Arizona	1993 to 1995	2,000 to 2,500	Mixed ponderosa pine
Simons et al. 2000	21	2.2	7.0 ^d	9	16	Coastal mountains, Southern California	1996 to 1998	1,500 to 2,400	Montane conifer and montane desert
Weller 2000	15/15	8.5	nr	7	3	Northwestern California	nr	950 to 1,320	Mature Douglas-fir and white fir

nr = not reported

^a“Rank” represents the ordinal abundance rank of *M. thysanodes* among the species captured in a given survey. For instance, a rank of 5 indicates that *M. thysanodes* was the 5th most abundant species of bat captured.

^bHourly encounter rate given as number of *M. thysanodes* per 100 net-hours.

^cHourly encounter rate given as number of *M. thysanodes* per 1000 linear net-meter-hours.

^dHourly encounter rate given as number of *M. thysanodes* per 100 hours.

^eHourly encounter rate estimated from total bat capture success and given as number of *M. thysanodes* per hour per 10 m² of nets.

Activity and movement patterns

Seasonal movements

The migratory patterns of *Myotis thysanodes* are not well known. They do maintain constant, low levels of body fat throughout the spring and summer and put on additional fat rapidly in late summer and early fall, suggesting that colonies migrate to winter hibernacula (Wilson and Ruff 1999). It is not known how far these hibernacula are from breeding grounds, but the distance is not likely to be great given the generally slow, maneuverable, energetically demanding flight of this species. It is therefore likely that *M. thysanodes* spend both summer and winter on National Forest System lands in Region 2. On a small scale in their northern range (e.g., South Dakota, Wyoming, and northern Colorado), it is generally thought that hibernacula are at lower elevations and/or further south than summer roosts. However, desert populations might actually migrate to higher locations in desert mountain ranges to hibernate because the temperatures are too warm at lower elevations (P. Brown unpublished data).

Studies suggest that *Myotis thysanodes* arrive at maternity roosts rapidly from mid-April to mid-May, after which populations become stable throughout the summer until a more gradual exodus peaking in September (O'Farrell and Studier 1975). These dates are very coarse, and specific migration timing undoubtedly fluctuates annually and geographically, with some spring migrants arriving before April and the last bats possibly not leaving a summer roost until October or November. Further, as suggested above, the destination of *M. thysanodes* migration is uncertain, and it is possible that different portions of the same cave or mine may be used as both summer roosts and winter hibernacula.

Daily activity and energy budgets

Most insectivorous bats exhibit a bimodal activity pattern each night, actively foraging early in the evening and again before dawn (Ekert 1982). On the whole, *Myotis thysanodes* appears to be most active for the first 1 to 2 hours after sunset, up to about 4.5 hours after sunset (O'Farrell and Studier 1980). Weller (2000) found that mean emergence time from day roosts (generally in tree snags) was 30.8 ± 1.9 minutes after sunset. O'Farrell and Studier (1975) suggest that the time of peak emergence is about 23 ± 0.6 minutes after sunset (range 12 to 32) and is most closely related to the time of sunset, rather than light intensity, rate of change in light intensity, or weather conditions. However,

other external factors may greatly influence nightly activity patterns, so such estimates should be viewed with caution. Studies have suggested that weather, particularly wind and rain, can greatly reduce overall nightly activity of small bats (O'Farrell and Bradley 1970, Ekert 1982, Kunz 1982, Grindal 1995, O'Farrell and Bradley 1970), but this is not uniformly supported for *M. thysanodes* (O'Farrell and Studier 1975). Time of first emergence may be affected by factors such as weather, with overcast conditions sometimes resulting in early first emergence while not affecting times of peak emergence (O'Farrell and Studier 1975). Bat researchers should be aware that even if weather conditions such as wind and rain do not greatly impact activity patterns, they can negatively impact observed activity, for instance by reducing capture rates by traditional survey methods such as mist-netting.

The daily energy budget for *Myotis thysanodes*, like most bats, is dominated by the requirements of flight, which comprise roughly 50 percent of daily energy use but account for only 8 percent of the time budget (Studier and O'Farrell 1980). Thus, small variations in time spent foraging have large repercussions on energy expenditures, which must then be compensated for by increased energy intake and/or decreased energy expenditure during roosting. Thus, the distance from roosting sites to foraging and drinking areas can have large repercussions on daily energy balance. Bats adapted to flight and foraging in cluttered areas, as is *M. thysanodes*, often forage and commute along habitat edges where cluttered areas (e.g., forests) abut open areas (e.g., meadows) (Fenton 1990, Grindal 1995). Since it has been demonstrated that *M. thysanodes* may remain away from maternity roosts all night, they are probably finding night-roosts proximate to foraging sites. This was the case for the radio-tagged female *M. thysanodes* in the San Diego County study. She commuted each evening from a rock crevice roost in chaparral to Jeffrey pine forest 1000 feet higher in elevation and 12.8 km distant, returning at dawn (Miner et al. 1996, Simons et al. 2000).

Myotis thysanodes may lose about 16 percent of its body weight during a day (12 hours) of normal roosting (Studier et al. 1970). Bats roosting in groups expend less energy to thermoregulate and consequently exhibit less weight loss during roosting periods (10.1 to 11.5 percent of body mass, mean = 10.9 percent) than those roosting singly (9.0 to 21.8 percent, mean = 15.8 percent) (Studier et al. 1970). Weight loss during roosting is partially due to defecation and urination early in the roosting period and to evaporative water loss that is related to environmental conditions in

the roost, especially ambient temperature (T_a). Water turnover was estimated to be nearly half the total body weight per day. In addition to energy balance issues, this results in large daily fluctuations in wing loading and, by extension, flight ability and energy expenditure during flight, over the course of 24 hours. The lowest wing loading occurs during the first flight of the evening, and the highest wing loading usually occurs after the initial foraging/drinking bout. Female body composition (e.g., fat content, water content, lean dry body weight, and embryo/fat-free body weight), and thus wing loading and energy expended on flight, also fluctuates significantly over reproductive stages (O'Farrell and Studier 1976).

Evidence suggests that *Myotis thysanodes* may be a facultative homeotherm, since patterns of thermoregulation can vary with breeding status, T_a , and roosting situation (Studier and O'Farrell 1976, O'Farrell and Studier 1980). Also, these bats can fly at low T_a and body temperature (T_b ; Wilson and Ruff 1999). The thermoneutral zone appeared to be at ambient temperatures ranging from 32.5 to 34.5 °C (O'Farrell and Studier 1970 in O'Farrell and Studier 1980). T_b is regulated more during mid-pregnancy and lactation and at times when the energy required for thermoregulation is not excessive (i.e., closer to the thermoneutral zone). Altenbach (personal communication 2003) has observed torpid female *M. thysanodes* in late stages of pregnancy roosting in cool mines. Energy demands, and thus physiological stress, of female bats are much higher during lactation (346 cal/day) than late pregnancy (78 cal/day; O'Farrell et al. 1971). Individual bats frequently shift from regulating to conforming and vice versa depending on environmental and physiological conditions. They can cut energy costs during roosting in half by shifting to thermo-conforming at temperatures below 16 °C. Further, since minimum T_b required for flight appears to be relatively low (on the order of 24 °C), *M. thysanodes* might be capable of some winter flight and potentially migrate to suitable habitat when weather becomes inhospitable, but no formal estimate of the energetic costs of flying are available.

Habitat

Vegetation types

Myotis thysanodes appear to use a fairly broad range of habitats (Cryan 1997). The most common habitats in which this species has been found are oak, pinyon, and juniper woodlands or ponderosa pine forest at middle elevations (Davis 1966, Barbour and Davis

1969, O'Farrell and Studier 1980, Cockrum et al. 1996, Wilson and Ruff 1999, Ellison et al. 2004). They also appear to use deserts (Cockrum et al. 1996), grasslands, and other types of woodlands. When trying to generalize all published information, one observes that *M. thysanodes* is mostly found in dry habitats where open areas (e.g., grasslands and deserts) are interspersed with mature forests (usually ponderosa pine, pinyon-juniper, or oak), creating complex mosaics with ample edges and abundant snags. This can take a variety of forms in Region 2, where open areas are likely represented by short and mixed-grass prairie, sagebrush and other xeric shrublands and forests, including a variety of low and mid-elevation pine and mixed-conifer types, some not adequately studied in other areas (e.g., lodgepole pine and Douglas-fir in addition to ponderosa and pinyon-juniper). Ideal habitat includes nearby water sources (see Water resources below) and suitable cliff or snag roost habitat (see Roosts below).

To gain a better idea of the variety of *Myotis thysanodes* habitat use, specific studies have indicated the following (see **Table 2**):

- ❖ A two year survey effort in northern Arizona suggested that ponderosa pine forest was used preferentially over pinyon and juniper (Herder 1998). This study resulted in 142 *Myotis thysanodes* captured in mist nets, harp traps, and trip lines placed over open water sources, of which 135 (3.75 per net night) were captured in ponderosa pine forest, six (0.46 per net night) in pinyon-juniper woodlands, and one (0.10 per net night) in desert scrub-sagebrush. This occurred despite the fact that the highest overall capture success was in pinyon-juniper woodland. These habitats were roughly altitudinally segregated, with shrub communities predominantly below 1400 m, pinyon and juniper communities between 1,400 and 1,800 m, and ponderosa pine communities over 1,800 m.
- ❖ In the Tonto National Forest, Agyagos et al. (1994) found *Myotis thysanodes thysanodes* to be much more abundant in montane conifer forest (particularly ponderosa pine) than in all other habitat types.
- ❖ The Arizona Game and Fish Department (1997) stated that those desert and shrubland areas used by *Myotis thysanodes*

were invariably within an hour flight of forested or riparian areas, including oak and pinyon woodlands.

- ❖ Ellinwood (1978) reported limited *Myotis thysanodes* captures, all of which were located in pinyon and juniper woodlands.
- ❖ Davis (1966) reported *Myotis thysanodes* foraging activity in oak forest in Texas.
- ❖ O'Farrell and Studier (1980) reported *Myotis thysanodes* captures over water troughs in creosote and burro bush shrubland in southern Nevada.
- ❖ Jones (1965) showed evidence of *Myotis thysanodes* use in a variety of evergreen forests in New Mexico and Arizona.
- ❖ Williams (1968) reported *Myotis thysanodes* use of sagebrush grasslands in Washington.
- ❖ Genter and Jurist (1995) documented *Myotis thysanodes* use of open semi-desert areas to dry ponderosa pine forest.
- ❖ Using radio telemetry, Brown and Berry (1998) and Miner et al. (1996) found that *Myotis thysanodes* roosted in cliff faces in dry chaparral and flew to foraging sites in pine/oak woodland.
- ❖ Brown and Berry (2000) documented a maternity colony of over 200 *Myotis thysanodes* in a mine in the Mojave Desert that was in creosote bush scrub at 600 m elevation.

Elevation

Myotis thysanodes appear to range in elevation between roughly 1,200 and 2,100 m, and they can be found up to 2,850 m in spruce-fir forest in New Mexico (Barbour and Davis 1969, Arizona Game and Fish Department 1997). A similar elevation range of 1,340 to 1,890 m was reported for *M. t. thysanodes* in Arizona (Agyagos et al. 1994). They have occasionally been reported from elevations of less than 150 m in coastal areas of California (Orr 1956), including at sea level on San Clemente Island off the southern coast of California (Von Bloeker 1967, Brown 1980).

Mist-netting activities in the southern Black Hills conducted by Cryan (1997) and Cryan et al. (2000) indicated mean elevations of capture for male *Myotis thysanodes pahasapensis* (mean = 479 m; STDV = 34 m; N = 202) were significantly higher than for reproductive females (mean = 408 m; STDV = 66 m; N = 22; $P < 0.001$). This trend has been suggested for other bats and is likely related to the energetic advantages gained by raising young in relatively warmer and insect-rich lowland environments (see citations in Cryan 1997).

Water resources

Daily water loss in bats is extreme compared to other mammals, largely due to the respiratory demands imposed by flight (Studier and O'Farrell 1980). Perhaps partially for this reason, the renal function of insectivorous bats appears to allow greater urine concentrating ability than suggested simply by their size and habitat use; and within this group of bats, renal function appears to be well correlated with the relative aridity of the predominant habitat (Geluso 1980). Bats in arid environments have kidneys with more prominent medullae than those in more mesic regions. Although found in a variety of habitats, *Myotis thysanodes* appears to have a lower urine concentrating ability than most bats (Geluso 1980), suggesting a predisposition to more mesic environments or environments where persistent sources of drinking water are readily available. Dependence on nearby water sources is also supported by the fact that roost sites have been shown to be located closer to stream channels than expected by chance (Weller and Zabel 2001). Brown and Berry (2000) found that the closest sources of open water were 16 km from a *M. thysanodes* roost in creosote bush scrub, suggesting that desert populations may have less dependence on proximate drinking water, perhaps due to as yet undescribed physiological adaptations.

A number of factors contribute to the ability of bats to use specific water sources. The body size and flight characteristics (e.g., speed and maneuverability) of individual bat species can determine the accessibility to water bodies of varying size and vegetative cover. For example, large, fast-flying bats, usually with limited maneuverability, are more likely to be encountered at large, uncluttered bodies of water, because they need long, open "swoop zones" and cannot effectively navigate through dense overhanging vegetation. Smaller bats, such as *Myotis thysanodes*, can be seen at a wider variety of water bodies, because they need

a minimal swoop zone and can maneuver through vegetative clutter. Such species can regularly use water sources as small as cattle stock tanks (Herder 1998) or persistent forest seeps.

Roosts

Roost types: Suitable roosting sites are a critical habitat component, the availability of which can determine population sizes and distributions (Humphrey 1975, Kunz 1982). Maternity roosts, diurnal roosts, nocturnal roosts, and winter hibernacula must all be considered. Throughout their range, *Myotis thysanodes* use caves, mines, and buildings as maternity colonies, solitary day and night roosts, and hibernacula (Musser and Durrant 1960, Davis 1966, Easterla 1966, Judd 1967, O'Farrell and Studier 1980, Perkins et al. 1990, Ellison et al. 2004). They also use bridges and rock crevices as solitary day and night roosts (Davis 1966, Miner et al. 1996, Brown and Berry 1998, Herder 1998), and they may hibernate in crevices (Christy and West 1993). They regularly roost underneath bark and inside hollows of tree snags, particularly ponderosa pine and Douglas-fir in medium stages of decay (Kurtzman 1994, Morell et al. 1994, Murphy 1994, Rasheed et al. 1995, Chung-MacCoubrey 2001, as cited in Cryan 1997). This may represent the primary daytime roosting structure in some areas of Region 2, including the Black Hills (Weller and Zabel 2001). Finally, in one study, *M. thysanodes* were found to use lava flows (Herder 1998), but this is likely atypical.

As the reader can tell from the above paragraph, there is much variation in roost selection by *Myotis thysanodes*. The pattern of this variation and its underlying causes are unclear. It likely results from a combination of factors, including the relative quality and availability of different roost types, the habitat structure surrounding roosts, prevailing environmental factors (e.g., temperature, wind), proximity to water and foraging areas, and predator avoidance (Kunz 1982, Lewis 1995). One of the most important factors driving roost selection is likely thermal regime (Kunz 1982), and it is possible that, at the distributional scale, *M. thysanodes* varies its roost choices in part on this basis. For instance the prevalence of crevice roosting found in arid climates may be a partial function of the high daytime temperatures in such areas, making maintenance of high daytime roost temperatures less restrictive. All eight *M. thysanodes* radio-collared in the Black Hills of Region 2 were found roosting in rock crevices in or near rock ridges or steep-walled canyons (Cryan 1997). These roost sites typically had southern exposure

(maximizing thermal heating) and were located in low-elevation forests (e.g., ponderosa pine) bordering oak and juniper woodlands. This interpretation is largely hypothetical, and without further information the reader should not interpret it as being the primary relationship affecting in roost choice.

In northern California it appears that male and female *Myotis thysanodes* use tree snags exclusively for day roosts (Weller and Zabel 2001). In areas where tree roosting is the norm, vegetative structural complexity of habitat around roost sites is likely more important than plant species composition or general topographic features in determining local distribution. *Myotis thysanodes* in the Weller and Zabel study chose roost areas with a higher density of large snags (i.e., 8.3 ± 0.8 snags ≥ 30 cm diameter at breast height per 0.1 ha) than surrounding forest (2.9 ± 0.3 per 0.1 ha; $P = 0.002$) and lower canopy cover (78.5 ± 2.6 percent) than surrounding forest (89.2 ± 1.1 percent; $P = 0.004$), which are likely correlated variables. Thus, as in studies of other tree roosting bats, it appears that *M. thysanodes* roost trees are in open microsites in otherwise contiguous forests, not in the open (Vanhof 1995).

The best habitat model for predicting bat presence in an area contained only these variables (the number of snags ≥ 30 cm DBH combined and percent canopy cover), where increasing numbers of snags and decreasing canopy cover increased the probability of bat occurrence (Weller 2000). Abundance of large snags and low canopy cover allows more thermal heating of roosts, easier flight access to roosts, and the ability to readily switch roosts in the event of roost collapse, for predator avoidance, or to find more suitable microclimates (Kunz 1982, Lewis 1995, Weller 2000). In such circumstances, *Myotis thysanodes* have been known to switch roosts several times a week (e.g., every 1.72 ± 0.23 days; Weller and Zabel 1999). Roost snags also tended to be taller relative to the surrounding canopy than random snags, had a higher diameter at breast height than random snags, and were nearer to stream channels than randomly selected points. Since *M. thysanodes* tended to roost under loose bark, most roost snags were in decay classes 2 to 4 (Thomas et al. 1979). Roost snags were Douglas-fir, ponderosa pine, and sugar pine used in approximate proportion to their availability (the largest snags in the study area were predominantly Douglas-fir). The reader should note that these findings refer to roost trees only, and that a general thinning of canopy will probably not benefit *M. thysanodes*, because their use of habitat includes many other factors, as discussed in this and subsequent sections.

Within-roost microsites: Microhabitat requirements of *Myotis thysanodes* within suitable cave and mine roosts have not been well studied. They tend to roost in open areas in tightly packed groups (Arizona Game and Fish Department 1997, Wilson and Ruff 1999), often in shallow pockets in the ceiling. In houses, maternity roosts usually occur in tightly packed clusters in open areas of attics (e.g., along ceiling joists), but they may also occur in cracks between beams (O'Farrell and Studier 1980) or in crevices between the chimney and building (P. Brown personal observation).

As with other bats, *Myotis thysanodes* likely select roosts based on temperature regimes. Maternity colonies are generally quite warm, to minimize thermoregulatory expenditures of pregnant and lactating females and developing young. Groups of roosting *M. thysanodes* often switch locations within roost sites, probably to find appropriate microclimates for thermoregulatory purposes. In attics, reproductive females appeared to seek out warm (not hot) microclimates throughout the summer, but they shifted to cooler microclimates with the approach of fall migration (O'Farrell and Studier 1980). Ideal day roosts for large numbers of bats often have a variety of microclimates within them, so bats are able to behaviorally thermoregulate by moving to different locations within the same roost structure.

Hibernacula: Few hibernacula have been well documented, but those that have are generally cool and usually in caves or mines with little temperature fluctuation throughout the winter, facilitating hibernation at a uniformly low metabolic rate. A few bats were reported hibernating in mines in Arizona (Cockrum et al. 1996) that were cool (e.g., 16.7 °C and 21.7 °C) and damp (no indices given). They have also been discovered hibernating in buildings and mines along the coast range north of San Francisco Bay (Pierson 1998). Unlike other bats that may aggregate in high numbers to hibernate, *Myotis thysanodes* has been shown to hibernate in small numbers, at least in the Black Hills (Martin and Hawks 1972, Tigner 1997 as cited in Cryan 1997).

Roost fidelity: Roost site fidelity varies among bats, but it is likely to be inversely related to roost availability and directly related to roost permanence (Kunz 1982, Lewis 1995 as cited in Cryan 1997, Weller and Zabel 2001). The roost site fidelity of *Myotis thysanodes* appears to vary across its range and is likely related to the main roosting structures in a given geographic area. Roosts in relatively permanent structures, such as caves, buildings, and rock crevices, appear to elicit high fidelity while roosts in trees do

not (Lewis 1995, Weller and Zabel 2001). Bats using spatially abundant but impermanent roosts (e.g., tree foliage or snags) are more closely tied to a home range in which a variety of roosts are used, than are bats that roost in relatively permanent but sparse habitat features (e.g., caves). This is suggested by the studies in California that showed low fidelity to individual roost snags but high fidelity to the specific areas in which those snags occurred, as indicated by consecutive roosts snags that were close together (i.e., 254 ± 61 m; Weller and Zabel 2001). In such an area, shifting between roosts occurs on a daily basis (Weller 2000), so specific roost trees, although heavily used over a longer period of time, may not be used at all on a given night (Weller 2000). Additionally, Cryan (1997) found evidence that some *Myotis* species roosted in a variety of structures, making characterization of optimal roosting habitat complex.

Nursery colonies likely remain more stable, since lactating females with pups are less likely to shift day roosts. Chung-MacCoubrey (1996) investigated roosting habits of pregnant or lactating female *Myotis thysanodes* captured in pinyon-juniper habitat in New Mexico. This study suggested that maternal *M. thysanodes* showed roost fidelity to colonial roosts in living and dead ponderosa pine trees with lightening or wind damage. Such trees were generally located near the boundary of ponderosa pine stringers in pinyon-juniper habitat.

Gender segregation: Aside from the fact that they roost separately, males are likely to choose summer roosts with different characteristics than females, a trait that may be true of many bat species. Specifically, females may choose warmer roost sites because they have more thermoregulatory demands, as they must maintain a relatively high metabolism during gestation and lactation (Kunz and Nagy 1988). In contrast, males can use daily torpor as a means of energy conservation and so may use cooler roost sites. There is some evidence from different portions of their range that male *M. thysanodes* roost at higher elevations than females during the spring and summer months (Cockrum et al. 1996).

Seasonal and life history shifts

In the temperate portion of its range, *Myotis thysanodes* likely migrates short distances to winter hibernacula that are lower in elevation and/or more southern than summer roosts. In southern desert areas, bats may actually move to higher elevations in search of cooler temperatures for hibernation. Migration events are relatively quick, synchronous, and closely tied to

breeding; spring migration is probably more so than fall migration, and there is likely variation related to seasonal weather patterns. In New Mexico, bats will usually arrive at their maternity roost from mid to late April and depart sometime in September (O'Farrell and Studier 1975). However, the destination of *M. thysanodes* migration is uncertain, and it is possible that different portions of the same cave or mine may be used as both summer roosts and winter hibernacula. It has been suggested that *M. thysanodes* do not generally have sufficient fat reserves at the end of the breeding season to enter hibernation immediately after vacating maternity roosts and that they therefore may remain periodically active in the fall, or even all winter in temperate climates such as parts of New Mexico (O'Farrell and Studier 1975, 1976). This is supported by the ability of this species to fly at reduced body temperature (Studier and O'Farrell 1972 as cited in O'Farrell and Studier 1975).

Given that fetal development is closely tied to spring thermoregulatory history of pregnant females, O'Farrell and Studier (1975) suggest that the uniformity of spring migration and parturition dates are evidence that *Myotis thysanodes* roosting groups are annually coherent. In other words, all members of a given maternity colony likely roost in the same hibernacula, or at least congregate in a common location prior to spring arrival at the maternity colony. This suggests potentially low mixing between roost groups, and when combined with high inter-annual roost area fidelity, has implications for isolation of *M. thysanodes* populations.

Area requirements

Very few data are available on home range requirements for insectivorous bats and none for *Myotis thysanodes* in particular. Telemetry studies have shown great variability in the distances traveled by different species of bats (Kunz and Pierson 1994), which is due to a variety of intrinsic (e.g., body size, wing morphology, foraging strategy) and extrinsic (e.g., local topography, prey distribution, water sources, roost abundance, landscape mosaic) factors. Moreover, it has been argued that the concept of home range does not apply well to bats given their mobility and the apparent plasticity of foraging areas with respect to prey abundance (de Jong 1994).

With the above difficulties in mind, the nightly activity areas for individual *Myotis evotis* (similar in form and function to *M. thysanodes*; Bickham 1979, Reduker et al. 1983) were reported as approximately 38.3 ha (SE = 7.3 ha; n = 11) based on radio telemetry

in late summer (Waldien and Hayes 2001). This appears to be a reasonable estimate of home range size for *M. thysanodes*. However, *M. thysanodes* have been shown to travel farther from roosts than *M. evotis* in similar habitat (Miner et al. 1996), so their home ranges could be somewhat larger.

One must be very cautious in relying on such numbers when making management decisions because, as noted above, home range within a single species can vary due to a variety of environmental factors. For example, it is likely that *Myotis thysanodes* home ranges grow larger as insect abundance decreases over the course of a summer. de Jong (1994) showed that the "home range" of *Eptesicus nilssonii* increased substantially (from ~ 12 ha to over 700 ha) as insect abundance decreased over the course of a summer. With high insect abundance, bats hunted close to their day roost, but as insect abundance decreased, they foraged farther a field. This was mitigated somewhat by reproductive status, because lactating females remained relatively close to the roost regardless of prey availability. It may also be biased by availability of water, since bats appear to forage preferentially near, but not necessarily over, water (Waldien and Hayes 2001). This is likely driven as much by the relative availability of prey in these locations as any other factor.

A somewhat different way of conceptualizing the area requirements of bats is to consider the distance that they will travel from a roost to a foraging area (see also the discussion below on landscape context). Such distances depend on the species. Strong, direct fliers (e.g., *Lasiurus cinereus*) may be capable of longer commuting flights than slow, agile fliers (e.g., *Myotis evotis*) for the same relative energy expenditure. However, the distance any one species will travel appears to be fairly plastic, and similar species may range over different distances. For instance, as summarized by Pierson (1998), recorded one-way distances from roost to foraging areas ranged from about 40 km (*M. grisescens*) to less than 1 km (*M. evotis*). Given their wing morphology, *M. thysanodes* would likely fall on the short end of this scale, although one telemetered female did commute at least 8 km one way to a foraging area (Miner et al. 1996, Brown and Berry 1998). The main message to remember is that the farther a roost is from a foraging area, the greater are the energetic demands placed on the bats and (all else being equal) the less suitable the habitat mosaic. The point at which this distance becomes critical depends on a host of factors (e.g., species, habitat structure, forage quality), but there is undoubtedly some distance at which the energetic cost of commuting to foraging

sites outweighs feasible energy intake and makes a site unsuitable for supporting a viable bat population.

Landscape context

The significance of the spatial relationship of foraging, night-roosting, and day-roosting sites is poorly understood for most bats. Generally speaking, roost sites are near, but geographically separate from, foraging sites (Waldien and Hayes 2001). The fact that bats do not necessarily forage around the roost makes intuitive sense, because these two areas are selected for different qualities. Roost sites are chosen for roost qualities (e.g., thermal regime, accessibility, predator avoidance), and foraging areas are chosen for prey availability (e.g., insect abundance, vegetative structure, access to drinking water). However, the extent to which roosting and foraging areas are geographically proximate contributes to the quality of those sites for supporting viable bat populations, because the delicate energy balance of bats is impacted most significantly by time spent in flight, which is directly related to time spent foraging and commuting to foraging areas (Studier and O'Farrell 1980). Thus, ideal areas for *Myotis thysanodes* (and many other bats) will contain a mosaic of foraging habitat, still water sources, and roost structures that are proximate to each other over a large enough area to accommodate shifts in local prey abundance, as noted in the previous section on area requirements (Pierson 1998).

Food habits

Diet

Generalized food habits from Black (1974) are summarized by O'Farrell and Studier (1980). Some studies have suggested that *Myotis thysanodes* consumes mostly beetles (Black 1974, Rainey and Pierson 1996), but others in the Pacific Northwest have suggested mainly moths (Whitaker et al. 1977). Anecdotal information supports a diet largely of beetles and moths (Turner and Jones 1968, Arizona Game and Fish Department 1997), and fly larvae are eaten in captivity (Banfield 1975). A more detailed diet analyses (Warner 1985) suggested that *M. thysanodes* was somewhat opportunistic, feeding on a variety of insect classes when they became abundant, but that beetles always comprised a large portion of the diet. Of 68 diet samples collected over two summers, 90 percent contained the remains of coleopterans, followed by lepidopterans (62 percent), dipterans (53 percent), neuropterans (24 percent), hymenopterans and homopterans (9 percent each), and others (9 percent). Most species in this

study regularly consumed moths, but *M. thysanodes* and *Antrozous pallidus* were the only two bats with less than a 50 percent frequency occurrence of moths in their diets. In a limited sample, Whitaker et al. (1977) found a variety of insect classes in stomachs of *M. thysanodes*, with nearly 50 percent of total volume accounted for by potentially flightless taxa (Phalangida, Araneida, and Grylidae). All things considered, it is distinctly possible that there is geographic variation in *M. thysanodes* diet at both the distribution and local levels, likely due to variation in prey availability (Kunz 1982), but not enough information has been collected and reported to draw any conclusions.

Foraging

O'Farrell et al. (1971) estimate that *Myotis thysanodes* must assimilate 4.39 kcal per day to maintain caloric balance. A higher assimilation is required to gain needed fat deposits in preparation for winter hibernation, perhaps on the order of 4.58 kcal per day, which is what bats in this study assimilated in late September. *Myotis thysanodes* appears to emerge late in the evening compared to other bats, generally 1 to 2 hours after sunset (Cockrum and Cross 1964, Weller and Zabel 2001). In desert areas, a maternity colony of *M. thysanodes* emerged within an hour of sunset (Brown and Berry 2000); this was consistent with a radio-telemetry study of this species in southern California mountains (Miner et al. 1996).

Early studies (Black 1974, Banfield 1975) speculate that *Myotis thysanodes* hunt insects on the wing, usually over vegetative canopy from sunset until midnight. However, the wing morphology of *M. thysanodes* is indicative of dexterous, low-speed flight suitable for foraging in areas with much vegetative clutter, suggesting that these bats may glean insects from vegetation (O'Farrell and Studier 1980), probably near the top of the forest canopy (Miner et al. 1996). Flight speeds of *M. thysanodes* in restricted environments have been estimated at roughly 13.8 km per hour (range: 12.8 – 15.8), which is slightly lower than expected based on forearm length (Hayward and Davis 1964). This reduced speed to size ratio also suggests a gleaning mode of foraging wherein slow-speed maneuverability is necessary for capturing prey and is seen in other gleaning bats, most notably the pallid bat (*Antrozous pallidus*).

It has been suggested that *Myotis thysanodes* has other physiological adaptations suited to a gleaning mode of foraging, including a larger brain to facilitate highly maneuverable flight and dexterous control of

the tail membrane for capturing prey (Findley 1972, Findley and Wilson 1982). The fringe of uropatagial hairs may also aid in such prey capture, as they are connected to a muscle in the tail membrane that is unique to *M. thysanodes* and that may allow the hairs to flare perpendicular to the uropatagium, thus preventing escape of insects once they are ensnared in the tail membrane (Glass and Gannon 1994). It is also possible that such hairs may help glean insects by adding tactile sensitivity to the tail (Glass and Gannon 1994).

Many species of bats, including *Myotis thysanodes*, forage over bodies of water, as insect abundance (e.g., mosquitoes) is often much greater in these areas (Thomas and West 1991 as cited in Christy and West 1993, Grindal et al. 1999). Also, it has been shown that many bats preferentially forage along forest or field edges (Furlonger et al. 1987, Fenton 1990, Grindal 1995, Ellison et al. 2004). This makes ecological sense because forests and forest edges have been shown to support more insect biomass, abundance, and richness than adjacent open areas (Lewis 1970, Grindal 1995, Grindal and Brigham 1999), while edges have low spatial complexity relative to interior forest. Edge-foraging has been demonstrated for *M. thysanodes* in a radio-telemetry study in the Laguna Mountains of southern California (Miner et al. 1996, Brown and Berry 1998). Given their wing morphology, echolocation patterns, and purported gleaning mode of foraging, it is likely that they are adapted to forage and fly in vegetatively cluttered environments, which means they probably forage in interior forest and/or along forest edges. Further, Coleopterans, which are their chief prey taxa (see above), may be less abundant in clearcuts and clearcut edges than in forested landscapes where they are otherwise prevalent (Grindal and Brigham 1999). If prey distribution at least partially determines foraging patterns of *M. thysanodes*, it stands to reason that these bats would preferentially forage in the forest, where beetles may be most abundant.

Water

In addition to foraging near water (see information above on foraging), most bats need open, still bodies of water to drink, and lactating females have additional water demands. Bats in general drink water by skimming the surface of open, flat bodies of water while in flight. It has been estimated that captive *Myotis thysanodes* on a mealworm diet experience a water turnover of almost half their total body water per day (O'Farrell et al. 1971), likely due in part to high dietary protein loads and high rates of evaporative water loss due to flight (McNab 1982). Therefore, *M. thysanodes*

must drink water shortly after emerging from day roosts each evening (Cross 1986 as cited in Christy and West 1993). Given their flying agility, it is likely that even very small watering holes have sufficient open surface area for them to drink. However, desert populations of bats may receive necessary water from prey and not have the same requirements for open drinking water as those in mesic environments, as evidenced by maternity colonies located in low desert scrub not near open water (Brown and Berry 2000).

Breeding biology

Breeding phenology

In New Mexico, *Myotis thysanodes* probably mates after females leave the maternity roost in the fall (O'Farrell and Studier 1973). Sperm are stored over-winter, and ovulation, fertilization, and implantation occur in late April to mid-May. Gestation lasts 50 to 60 days, and young are born over about a two-week period in late June to early July (i.e., between about June 28 and July 3; Barbour and Davis 1969, O'Farrell and Studier 1975). Although no formal studies have investigated *M. thysanodes* breeding phenology in other parts of the country, captures of pregnant and lactating bats elsewhere in their range suggest that the timing of reproduction may be fairly similar throughout their range (Miller and Allen 1928, Dalquest 1947, Cockrum and Ordway 1959, Barbour and Davis 1969, Easterla 1973). For instance, lactating females were captured between about July 4 and July 23 in northern Arizona, and young of the year began to be captured after the middle of July (Herder 1998).

Young are capable of limited flight 16.5 days after parturition, and flight becomes indistinguishable from adults by 20.5 days (O'Farrell and Studier 1973, O'Farrell and Studier 1980). Young achieve full adult body dimensions by 21 days of age, at which point they are indistinguishable from adults except by epiphysial closures. A complete relation of age to body measurements is given by O'Farrell and Studier (1973). Juvenile *Myotis thysanodes* leave the maternity roost soon after weaning, while the adult females may remain until late summer or early fall departure to hibernacula (O'Farrell and Studier 1975).

Due to the high energetic demands of flight, their small body size, their restrictive nocturnal feeding habits, and thermoregulation in temperate climates, *Myotis thysanodes*, and bats in general, face difficulties in maintaining a positive daily energy balance. This is particularly true of pregnant and lactating females,

who have the substantial added burden of fetal growth and milk production, respectively. One common way for bats to maintain a positive energy balance is by periodically becoming heterothermic while roosting (McNab 1982). This strategy entails special tradeoffs in breeding females, since fetal development and milk quality are directly affected by parental metabolism and body temperatures (McNab 1982, Tuttle and Stevenson 1982). Pregnant *M. thysanodes* females maintain homeothermy during early and middle pregnancy, but shift to heterothermy about 37 days into pregnancy to conserve energy; this energy appears to be shunted directly to the fetus, resulting in a period of rapid fetal growth prior to birth (Studier et al. 1973). This postponement of fetal growth makes sense in an energy-limited species whose ability to fly, and consequently ability to forage effectively, is directly dependent on fetal size. Altenbach (personal communication 2003) has observed females in later pregnancy stages in full torpor in what he describes as embryonic diapause. Somewhat less intuitively, lactation is even more energetically demanding for bats than any point during pregnancy (Studier et al. 1973).

Breeding behavior

Maternity colonies are usually found in caves, mines, and sometimes in buildings (Wilson and Ruff 1999). They appear to consist entirely of adult females and pups and range in size from dozens of adult bats to several hundred or more (Barbour and Davis 1969, O'Farrell and Studier 1975, O'Farrell and Studier 1980, Agyagos et al. 1994). During the weeks prior to parturition, *Myotis thysanodes* females become very secretive and difficult to find in the roost (O'Farrell and Studier 1973); this may have important ramifications for timing of survey work. Whereas they normally roost in fairly open areas within the roost structure, prior to birth they form small, isolated groups in smaller cracks. O'Farrell and Studier (1973) reported a resident cluster of 60 or more suddenly "disappearing"; further searching revealed this isolation behavior. Also, during this pre-parturition period, they become even more sensitive to disturbance, making them very difficult to approach and accurately count.

Males usually roost separately from maternity colonies (O'Farrell and Studier 1975, O'Farrell and Studier 1980) and singly or in small groups. Males are completely segregated from females for all of the non-hibernating year, except for a brief mating period after young have been weaned. In studies conducted in Mohave County, Arizona, male bats segregate to form different and smaller spring and summer colonies than

female, maternity colonies, and these male aggregations occur at higher elevations than female roosts (Cockrum et al. 1996). In the temperate Black Hills of South Dakota, all *Myotis thysanodes* maternity roosts (and those of all other *Myotis* species in the study) were found at relatively low elevations to which they likely migrated from higher, cooler hibernacula sites (Cyran 1997, 2000). A similar trend was found among other *Myotis* species in the Washington Cascades and the Oregon Coast range (Thomas 1988).

Myotis thysanodes appear to exhibit high breeding site fidelity, returning to the same geographic areas year after year (Cockrum et al. 1996, Easterla 1973, Tigner 1997 as cited in Cyran 1997). However, they may change specific roosts within an area multiple times within a given season (Cyran 1997), theoretically to find optimal thermoregulatory or prey conditions (see further discussion under the Roosts section above)

Adult females appear to roost in a cluster separate from the juveniles although they do fly into the juvenile cluster regularly to nurse (O'Farrell and Studier 1973). Some level of communal care for young appears to occur in *Myotis thysanodes* maternity colonies. During each night when adults leave the roost to forage, several females remain in the roost with the pups (O'Farrell and Studier 1980). These individuals occasionally suckle pups and retrieve those that fall from the roost.

Fecundity and survivorship

Myotis thysanodes have only one young per year per female (Cockrum 1955, Barbour and Davis 1969). Daily energy balances of pregnant and lactating female bats, including *M. thysanodes*, appear to be very restrictive and may preclude the development of more than one offspring per litter (Studier et al. 1973). A large portion of breeding females become pregnant every year (O'Farrell and Studier 1975). In New Mexico, the adult-to-young parturition ratio in a maternity colony was nearly one (O'Farrell and Studier 1975). Age at first breeding is uncertain. There is no direct evidence to determine whether young breed the fall after parturition, but the lack of testicular activity in male young of the year suggests that *M. thysanodes* may not breed until their second year (O'Farrell and Studier 1980).

Neonate (i.e., newborn) mortality may be as low as 1 percent (O'Farrell and Studier 1973). Juvenile mortality (i.e., mortality through roughly the first year) is likely quite a bit higher, but no concrete data exist on adult or juvenile survivorship. Banding studies indicate life spans for *Myotis thysanodes* of up to

11 years (Paradiso and Greenhall 1967, Wilson and Ruff 1999), but due to the difficulties associated with band-recapture estimates and the fact that other North American *Myotis* species have been recorded at up to 34 years old (unpublished data), maximum longevity is likely somewhat longer.

Population demography

Spatial characteristics and genetic concerns

No studies have been conducted regarding the metapopulation dynamics or genetic differentiation among *Myotis thysanodes* populations. This would pose an interesting question for future research, as bats are highly mobile but also closely tied to limited roosting and foraging areas, thus having limited potential distribution and dispersal. For instance, the relative level of sympatry between the Black Hills subspecies (*M. t. pahasapensis*) and *M. t. thysanodes*, and thus the extent and validity of the subspecies, is largely unknown. Dewey (2000) is investigating interspecific and intraspecific variation in mitochondrial DNA for several species of myotis, including *M. thysanodes*, but there are no results at this time.

*Life history model**

Summary: Matrix models are designed to examine the intrinsic life history of a species, (i.e., evolved traits affecting reproduction, or the component of population persistence that is affected by factors internal to the species rather than external to the species [e.g., habitat availability or the impacts of disease]. Although initially developed for birds (Leslie 1945, 1966) and applied extensively to plants (Menges 1990, Bierzychudek 1995, Enright et al. 1999), they are very general models that can be applied successfully to nearly any taxon, including amphibians (Biek et al. 2002). The utility of matrix models in biology is primarily to gain insight into those transitions in the life cycle that are the keys to population dynamics (i.e., where are the “weak links” or vulnerable points in the life cycle?). Matrix models are not necessarily the only, or even the most appropriate, means for assessing whether populations are growing or declining, for assessing the likelihood of extinction, or for determining the impacts of specific habitat factors. For instance, consider that populations of an amphibian are declining due to the elimination of breeding ponds resulting from the introduction of a disease (an external influence). This does not impact

the structure of the model, since the intrinsic, evolved traits of the species are not altered (e.g., the remaining ponds and individuals may all have the same vital rates). The fact that specific populations may be in decline (i.e., violating the assumption of the population growth rate being approximately one, $\lambda \approx 1$) will not, by itself, change the relative importance of the different life stages. If such a decline is affecting one stage to an abnormally high degree, one can incorporate the altered vital rates (survival and fertility rates) with an adjusted model. What these models can do is to point to particular transitions in the life cycle that are most likely to have a strong effect on population dynamics. They can, for example, tell us that changing adult survival will have much greater impact on population dynamics than would a similar change in fertility.

The results of the *Myotis thysanodes* matrix model suggest that, all else being equal, the most critical life history parameter is the survival of breeding females. This further stresses the importance of maintaining viable maternity colonies and hibernacula. The sensitivity analysis suggests that, for relatively small absolute changes (e.g., +0.1, -0.05 change to a vital rate), the survival of reproductive females is the key to population viability. However, compared to life histories of amphibians or turtles, for example, fertilities are relatively more important. Based solely on this information, it appears important to manage for factors that affect this life stage, such as insuring persistence of maternity colonies. Moreover, the high sensitivity of λ to changes in survival and fertility of breeding females is likely an indication that in “good” years the response of the population will be largely determined by what happens to maternity roosts. Elasticity and partial elasticity analyses confirm the importance of breeding female survival, particularly survival through the first three age-classes.

Examining the effects of stochastic variation in vital rates suggested that altering the survival rates had a much more dramatic effect on λ than did altering the fertilities. Thus, populations of *Myotis thysanodes* appear somewhat tolerant to stochastic fluctuations in production of newborns (due, for example, to annual climatic change or to human disturbance), but they are more vulnerable to variations in survival. However, because of their small invariant litter size (1) and because of the relatively high sensitivity of λ to changes in fertility, these bats may also be particularly vulnerable to disturbance at birthing sites.

*This model was largely compiled by Dave McDonald and Takeshi Ise. The lead author was not associated with this effort except in a review capacity.

Model development: The life history described by Jones (1983) provided the basis for a life cycle graph (**Figure 5**) and a matrix population analysis with a post-breeding census (Cochran and Ellner 1992, McDonald and Caswell 1993, Caswell 2000) for *Myotis thysanodes*. The model has two kinds of input terms: P_i , describing survival rates, and m_i , describing fertilities (**Table 3**). Figure 6a shows the symbolic terms in the projection matrix corresponding to the life cycle graph. Figure 6b gives the corresponding numeric values. The model assumes female demographic dominance so that, for example, fertilities are given as female offspring per female. The population growth rate (λ) is 1.000 based on the estimated vital rates used for the matrix. Although this suggests a stationary population, the value is subject to the many assumptions used to derive the transitions and should not be interpreted as an indication of the general well-being and stability of the population. Other parts of the analysis provide a better guide for assessment.

Sensitivity analysis: A useful indication of the state of the population comes from the sensitivity and elasticity analyses. **Sensitivity** is the effect on λ of an **absolute** change in the vital rates (a_{ij} , the arcs in the life cycle graph [**Figure 5**] and the cells in the matrix, A [**Figure 6**]). Sensitivity analysis provides several kinds of useful information (see Caswell 2000). First, sensitivities show “how important” a given vital rate is to λ or fitness. For example, one can use sensitivities to assess the relative importance of survival (P_i) and reproductive (F_i) transitions. Second, sensitivities can be used to evaluate the effects of inaccurate estimation of vital rates from field studies. Inaccuracy will usually be due to paucity of data, but it could also result from the use of inappropriate estimation techniques or other errors of analysis. In order to improve the accuracy of the models, researchers should concentrate additional effort on transitions with large sensitivities. Third, sensitivities can quantify the effects of environmental perturbations, wherever those can be linked to effects on stage-

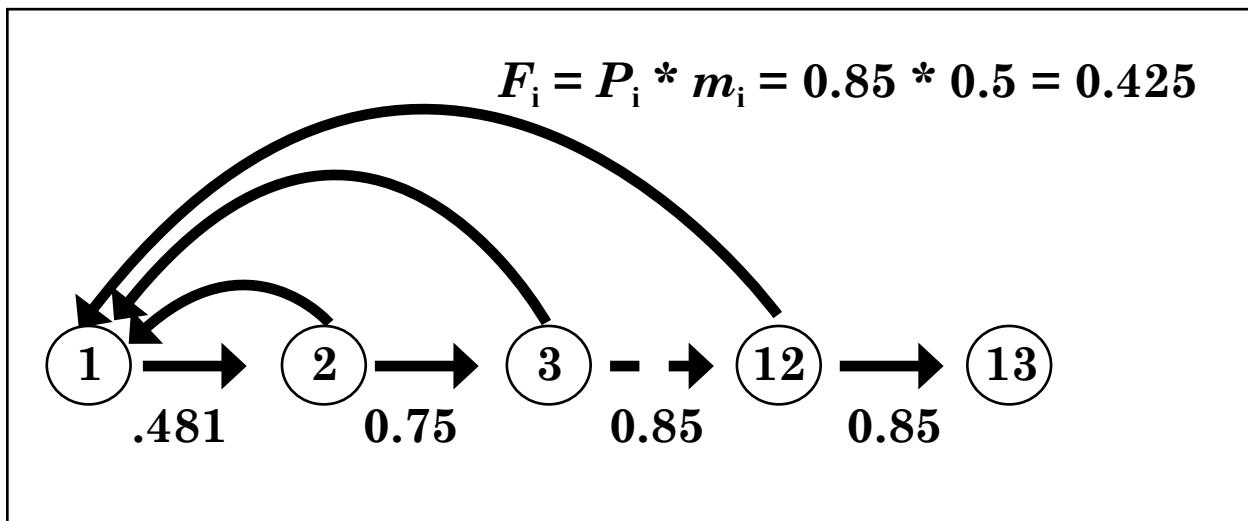


Figure 5. Age-classified life cycle graph for *Myotis thysanodes*. Reproductive arcs, F_i , emerging from Nodes 2 through 12 include terms for survival of female parent (P_i) as well as number of female offspring per female (m_i). Note that the ellipsis of Nodes 4 through 11 are identical (all with $P_i = 0.85$, $F_i = 0.425$).

Table 3. Parameter values for the component terms (P_i and m_i) that make up the vital rates in the projection matrix for *Myotis thysanodes*. Numeric values are based on information in Jones (1983) and expert opinion (see text).

Parameter	Numeric value	Interpretation
m	0.5	Number of female offspring produced by a female
P_{21}	0.481	Annual survival rate of newborn females
P_{32}	0.75	Annual survival rate of females at age of first reproduction
P_a	0.85	Annual survival rate of fully developed, reproductive females

a	1	2	3	4	5	6	7	8	9	10	11	12	13
1		$P_{32}m$	$P_a m$										
2		P_{21}											
3			P_a										
4				P_a									
5					P_a								
6						P_a							
7							P_a						
8								P_a					
9									P_a				
10										P_a			
11											P_a		
12												P_a	
13													P_a

b	1	2	3	4	5	6	7	8	9	10	11	12	13
1		0.375	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	
2		0.481											
3			0.75										
4				0.85									
5					0.85								
6						0.85							
7							0.85						
8								0.85					
9									0.85				
10										0.85			
11											0.85		
12												0.85	
13													0.85

Figure 6. The input matrix of vital rates (\mathbf{A} , with cells a_{ij}) corresponding to the *Myotis thysanodes* life cycle graph (**Figure 5**), given in both a) symbolic format and b) numeric format. Numeric values are based on information in Jones (1983) and expert opinion (see text).

specific survival or fertility rates. Fourth, managers can concentrate on the most important transitions. For example, they can assess which stages or vital rates are most critical to increasing λ of endangered species or the “weak links” in the life cycle of a pest. **Figure 7** shows the “possible sensitivities only” matrix for this analysis (one can calculate sensitivities for non-existent transitions, but these are usually either meaningless or biologically impossible — for example, the sensitivity of λ to moving from Age-class 3 to Age-class 2).

In general, changes that affect one type of age class or stage will also affect all similar age classes or stages. For example, any factor that changes the annual survival rate of Age-class 2 females is very likely to

cause similar changes in the survival rates of other “adult” reproductive females (those in Age-classes 3 through 12). Therefore, it is usually appropriate to assess the summed sensitivities for similar sets of transitions (vital rates). For this model, the result is that the summed sensitivity of 1 to changes in the survival of reproductive females is important. *Myotis thysanodes* shows large sensitivity (0.770, 48 percent of total) to changes in the survival sensitivity. First-year survival is 0.381 (24 percent of total), and the summed sensitivity in fertility is 0.441 (28 percent of total). The major conclusion from the sensitivity analysis is that the survival of reproductive females is the key to population viability. Compared to life histories of amphibians or turtles, however, the fertilities are more important (cf. Blanding’s turtle or spotted frog).

	1	2	3	4	5	6	7	8	9	10	11	12	13
1		0.088	0.066	0.056	0.048	0.041	0.034	0.029	0.025	0.021	0.018	0.015	
2	0.381												
3		0.200											
4			0.144										
5				0.116									
6					0.092								
7						0.072							
8							0.054						
9								0.040					
10									0.027				
11										0.017			
12											0.008		
13												0.000	

Figure 7. Possible sensitivities only matrix, S_p (blank cells correspond to zeros in the original matrix, A). The three transitions to which the λ of *Myotis thysanodes* is most sensitive are highlighted: first-year survival (Cell $s_{21} = 0.381$), the survival of females at age of first reproduction ($s_{32} = 0.200$), and the survival of Age-class 3 ($s_{43} = 0.144$).

Elasticity analysis: Elasticities are useful in resolving a problem of scale that can affect conclusions drawn from the sensitivities. Interpreting sensitivities can be somewhat misleading because survival rates and reproductive rates are measured on different scales. For instance, a change of 0.5 in survival may be a big alteration (e.g., a change from a survival rate of 90 to 40 percent). On the other hand, a change of 0.5 in fertility may be a very small **proportional** alteration (e.g., a change from a clutch of 3,000 eggs to 2,999.5 eggs). Elasticities are the sensitivities of λ to **proportional** changes in the vital rates (a_{ij}) and thus largely avoid the problem of differences in units of measurement. The elasticities have the useful property of summing to 1.0. The difference between sensitivity and elasticity conclusions results from the weighting of the elasticities by the value of the original arc coefficients (the a_{ij} cells of the projection matrix). Management conclusions will depend on whether changes in vital rates are likely to be absolute (guided by sensitivities) or proportional (guided by elasticities). By using elasticities, one can further assess key life history transitions and stages as well as the relative importance of reproduction (F_i) and survival (P_i) for a given species.

Elasticities for *Myotis thysanodes* are shown in **Figure 8**. The λ of *M. thysanodes* is most elastic to changes in first-year survival (Age-class 1), followed by the survival of females at age of first reproduction (Age-class 2) and the survival of females at Age-class 3. The sensitivities and elasticities for *M. thysanodes* correspond exactly in the rank magnitude of transitions,

a phenomenon that is not always the case in other life histories (*cf.* Townsend's big-eared bat, plains killifish). The survival rates through the first three age classes are the data elements that warrant careful monitoring in order to refine the matrix demographic analysis.

Partial sensitivity and elasticity: Partial sensitivity and elasticity analysis assesses the impact on λ of changes in “lower-level terms” (Caswell 2000, pp. 218 and 232). Some transitions (e.g., the F_i) include lower-level component terms (P_i and m_i) related to the different kinds of transitions in the life cycle (e.g., survival, fertility, and breeding probability terms). Partial sensitivity results indicate that changes in the P_i (survival rates) will have by far the greatest impact on λ (78.9 percent of the total partial sensitivity). Changes in fertility (m_i) will have far less impact on λ (21.1 percent of the total partial sensitivity). Similarly, P_i terms account for 84.5 percent of the total partial elasticity, with 15.5 percent accounted for by m_i terms. Again, every aspect of the analysis suggests that *M. thysanodes* are most susceptible to habitat degradation that affects the survival of females.

Other demographic parameters: The stable (st)age distribution (SAD; **Table 4**) describes the proportion of each stage (or age class) in a population at demographic equilibrium. Under a deterministic model, any unchanging matrix will converge on a population structure that follows the SAD, regardless of whether the population is declining, stationary, or increasing. Under most conditions, populations not at

	1	2	3	4	5	6	7	8	9	10	11	12	13
1		0.088	0.066	0.056	0.048	0.041	0.034	0.029	0.025	0.021	0.018	0.015	
2	0.381												
3		0.200											
4			0.144										
5				0.116									
6					0.092								
7						0.072							
8							0.054						
9								0.040					
10									0.027				
11										0.017			
12											0.008		
13												0.000	

Figure 8. Elasticity matrix, E (remainder of matrix consists of zeros). The λ of *Myotis thysanodes* is most elastic to changes in first-year survival ($e_{21} = 0.1833$), followed by the survival of the females at the age of first reproduction ($e_{32} = 0.1503$) and the survival of the Age-class 3 ($e_{43} = 0.1222$).

Table 4. Stable age distribution (right eigenvector) for females. At the time of census, 29 percent of the individuals in the population should be newborns, with the remaining 71 percent of individuals being reproductive adults.

Age Class	Description	Proportion
1	First-year individuals	0.287
2	First reproduction ($F_i = 0.375$)	0.138
3	Reproductive ($F_i = 0.425$)	0.104
4	Reproductive ($F_i = 0.425$)	0.088
5	Reproductive ($F_i = 0.425$)	0.075
6	Reproductive ($F_i = 0.425$)	0.064
7	Reproductive ($F_i = 0.425$)	0.054
8	Reproductive ($F_i = 0.425$)	0.046
9	Reproductive ($F_i = 0.425$)	0.039
10	Reproductive ($F_i = 0.425$)	0.033
11	Reproductive ($F_i = 0.425$)	0.028
12	Reproductive ($F_i = 0.425$)	0.024
13	Maximum age class	0.02

equilibrium will converge to the SAD within 20 to 100 census intervals. For *M. thysanodes* at the time of the post-breeding annual census (just after the end of the breeding season), newborns represent 29 percent of the population, and the remaining 71 percent consists of adult stages.

The **reproductive values** (**Table 5**) can be thought of as describing the “value” of a stage as a seed for population growth relative to that of the first (newborn)

stage. The reproductive value of the first stage is always 1.0. A female individual in Age-class 2 is “worth” 2.1 female newborns, and so on (Caswell 2000). The reproductive value is calculated as a weighted sum of the present and future reproductive output of a stage discounted by the probability of surviving (Williams 1966). The peak reproductive value (2.3 at Age-class 3) is higher than that of the newborns (**Table 5**) but not dramatically higher, as it is in the plains leopard frog (peak of 2,470, driven by the dramatic rise in prospects

Table 5. Reproductive values for females. Reproductive values can be thought of as describing the “value” of an age class as a seed for population growth relative to that of the first (newborn or, in this case, egg) age class. The reproductive value of the first age class is always 1.0. The peak reproductive value is highlighted.

Age Class	Description	Reproductive value
1	First-year individuals	1.00
2	First reproduction ($F_i = 0.375$)	2.08
3	Reproductive ($F_i = 0.425$)	2.28
4	Reproductive ($F_i = 0.425$)	2.18
5	Reproductive ($F_i = 0.425$)	2.06
6	Reproductive ($F_i = 0.425$)	1.93
7	Reproductive ($F_i = 0.425$)	1.77
8	Reproductive ($F_i = 0.425$)	1.58
9	Reproductive ($F_i = 0.425$)	1.35
10	Reproductive ($F_i = 0.425$)	1.09
11	Reproductive ($F_i = 0.425$)	0.79
12	Reproductive ($F_i = 0.425$)	0.43
13	Maximum age class	0.00

for those females that make it through the severe gauntlet of first-year survival). We see that females that have bred once are the most important stage in the life cycle, with reproductive value declining slowly to the maximum age. The cohort generation time for *Myotis thysanodes* 5.5 years (SD = 2.9 years).

Stochastic model: We conducted a stochastic matrix analysis for *Myotis thysanodes*. We incorporated stochasticity in several ways, by varying different combinations of vital rates or by varying the amount of stochastic fluctuation (Table 6). Under Variant 1 first-year survival fluctuated (P_{21}). Under Variant 2 we varied the survival of all age classes, P_i . Each run consisted of 2,000 census intervals (years) beginning with a population size of 10,000 distributed according to the SAD under the deterministic model. Beginning at the SAD helps to avoid the effects of transient, non-equilibrium dynamics. The overall simulation consisted of 100 runs (each with 2,000 cycles). We varied the amount of fluctuation by changing the standard deviation of the random normal distribution from which the stochastic vital rates were selected. The default value was a standard deviation of one quarter of the “mean” (with this “mean” set at the value of the original matrix entry [vital rate], a_{ij} under the deterministic analysis). Variant 3 affected the same transitions as Variant 2 (P_i) but was subjected to slightly larger-amplitude variation (SD was 1/3.5 [= 0.286 compared to 0.25] of the mean). We calculated the stochastic growth rate, $\log\lambda_s$, according to Eqn. 14.61 of Caswell (2000), after discarding the first 1,000 cycles in order to further avoid transient dynamics.

The stochastic model (Table 6) produced two major results. First, altering the survival rates had much greater effect on λ than did altering the fertilities. For example, the median ending size under the varying survival of newborns under Variant 1 showed a decline to 1,419.7 from the starting size of 10,000. Varying the survival rates of all age classes under Variant 2 resulted in much more dramatic decline of median size (116.9). The slightly increased amplitude of variability under Variant 3 caused a further decline in median ending population size (67.4). This difference in the effects of stochastic variation is predictable from the sensitivities and elasticities. λ was more sensitive to changes in survival, P_i than it was to changes in the fertilities, F_i . Second, stochasticity has a negative effect on population dynamics. This negative effect occurs despite the fact that the average vital rates remain the same as under the deterministic model — the random selections are from a symmetrical distribution. This apparent paradox is due to the lognormal distribution of stochastic ending population sizes (Caswell 2000). The lognormal distribution has the property that the mean exceeds the median, which exceeds the mode. Any particular realization will therefore be most likely to end at a population size considerably lower than the initial population size. For *Myotis thysanodes* under the survival Variant 2, 29 out of 100 trials of stochastic projection went to extinction vs. 0 under the fertilities Variant 1. Variant 3 shows that the magnitude of fluctuation has a potentially large impact on the detrimental effects of stochasticity. Increasing the magnitude of fluctuation also increased the severity of the negative impacts — the number of extinctions

Table 6. Summary of five variants of stochastic projections for *Myotis thysanodes*.

	Variant 1	Variant 2	Variant 3
<u>Input factors:</u>			
Affected cells	P_i 1/4	P_i 1/4	P_i 1/3.5
S.D. of random normal distribution			
<u>Output values:</u>			
Deterministic λ	1.00004	1.00004	1.00004
# Extinctions/100 trials	0	29	72
Mean extinction time	—	1,278.0	1,339.5
# Declines/# survived populations	82/100	67/71	26/28
Mean ending population size	4,860.3	6,597.7	2,526.9
Stnd. deviation	7,736.7	31,654.4	6,183.9
Median ending population size	1,419.7	116.9	67.4
Log λ_s	-0.00104	-0.00346	-0.00555
λ_s	0.999	0.9965	0.9945
Percent reduction in λ	0.109	0.35	0.556

went from 29 in Variant 2 to 72 in Variant 3 when the magnitude of fluctuation was slightly amplified. These results suggest that populations of *M. thysanodes* are somewhat tolerant to stochastic fluctuations in production of newborns (due, for example, to annual climatic change or to human disturbance) and more vulnerable to variations in survival. Pfister (1998) showed that for a wide range of empirical life histories, high sensitivity or elasticity was negatively correlated with high rates of temporal variation. That is, most species appear to have responded to strong selection by having low variability for sensitive transitions in their life cycles. A possible concern is that anthropogenic impacts may induce variation in previously invariant vital rates (such as annual adult survival), with consequent detrimental effects on population dynamics. Because of their small invariant litter size (1) and because of the relatively high sensitivity of λ to changes in fertility, these bats may also be particularly vulnerable to disturbance at birthing sites.

Potential refinements of the models: Clearly, the better the data on survival rates, the more accurate the resulting analysis. Data from natural populations on the range of variability in the vital rates would allow more realistic functions to model stochastic fluctuations. For example, time series based on actual temporal or spatial variability, would allow construction of a series of “stochastic” matrices that mirrored actual variation. One advantage of such a series would be the incorporation of observed correlations between variations in vital rates. Where we varied F_i and P_i values simultaneously, we assumed that the variation was uncorrelated, based on the assumption that factors affecting reproduction

and, for example, overwinter survival would occur at different seasons or be due to different and likely uncorrelated factors (e.g., predation load vs. climatic severity or water levels). Using observed correlations would improve on this assumption by incorporating forces that we did not consider. Those forces may drive greater positive or negative correlation among life history traits. Other potential refinements include incorporating density-dependent effects. At present, the data appear insufficient to assess reasonable functions governing density dependence.

Community ecology

Few studies have looked at the actual consumption rate of wild insectivorous bats (none at *Myotis thysanodes* in particular), but those that have suggest rapid consumption of insects (Kunz 1982), with some consuming perhaps half their body weight in insects each night (Whitaker 1988). Therefore, they represent major predators of nocturnal insects, and depending on their abundance and concentration in a given area, they could have ecologically significant impacts on local insect communities.

Many bats, including *Myotis thysanodes*, forage in specific areas, particularly near water, and roost in areas that are geographically separate from foraging areas. Digestion and defecation generally occur during roosting, so bats could potentially play a role in nutrient distribution in forested ecosystems (Grindal 1995), particularly given the typically high nitrogen concentration of their feces (Rainey et al. 1992).

Predators and competitors

Although a variety of animals can prey upon bats, virtually no information is available regarding the type and level of predation for *Myotis thysanodes* in particular. In general, bats are not a focal prey item for any carnivore group, so it is likely that predation on bats occurs opportunistically from a variety of sources, and that it is not a significant mortality factor in many areas (Grindal 1995). Despite this generality, anecdotal information exists that predators (e.g., kestrels, saw-whet owls, western screech owls, weasels, feral pets, snakes) might contribute to roost site abandonment under certain situations (M. Austin personal communication 2004). Although aerial predation of some bats has been noted on occasion (M. Austin personal communication 2004), most predation occurs when bats are roosting or when those bats that forage by gleaning land to capture insects. Typical predators include small mammalian carnivores (e.g., raccoons, weasels, domestic cats), small raptors, owls, fish, bullfrogs, snakes, and deer mice (Christy and West 1993). Given the development of predator-prey interactions over evolutionary time, natural predation is not likely to result in large-scale shifts in bat populations unless accompanied by other extenuating factors, such as anthropogenic disturbance or climatic fluctuation. However, predation by introduced carnivores in isolated populations has the potential to cause local damage.

Surveys of roost sights and watering holes in a variety of habitats have shown that *Myotis thysanodes* coexists with a wide variety of other bat species including *M. evotis*, *M. volans*, *M. californicus*, *M. ciliolabrum*, *M. lucifugus*, *M. velifer*, *M. yumanensis*, *M. auriculus*, *Eptesicus fuscus*, *Pipistrellus hesperus*, *Lasionycteris noctivagans*, *Corynorhinus townsendii*, *Idionycteris phyllotis*, *Euderma maculatum*, *Lasiurus borealis*, *L. cinereus*, *Antrozous pallidus*, *Tadarida brasiliensis*, and *T. macrotis* (O'Farrell and Studier 1980). This list partially reflects the wide distribution and habitat use of *M. thysanodes*. It appears that competition with these species is minimized in part through niche partitioning in which *M. thysanodes* forages in cluttered areas and may glean from vegetation rather than capture insects in the air. Anecdotal information hints that when *M. thysanodes* roost in tree cavities, they may be forced from roost sites by diurnal avians, such as European starlings or jays (M. Austin, personal communication 2004).

Parasites and disease

Myotis thysanodes can host a variety of ectoparasites, which have been summarized by O'Farrell and Studier (1980), but they have very few endoparasites (Cain and Studier 1974 as cited in O'Farrell and Studier 1980). It is possible for such parasites to have severe effects on individuals with extreme infestations, but no literature has related any of these parasites to population-level declines in *M. thysanodes*. As with other bats, high parasite levels in communal roosts may cause *M. thysanodes* populations to change roosts (Lewis 1995). Although no specific information is available on which to draw conclusions regarding *M. thysanodes*, it is possible that once populations become stressed by other factors, such as human use of roosting caves, or are already declining for other reasons, the heretofore small impact of parasites on those populations could become more evident and potentially detrimental. It may therefore be valuable for managers to evaluate the health of captured bats relative to parasite loads, but we believe that this is a relatively low priority given the more pressing need of measures targeting habitat conservation.

There have been a few reports of individual *Myotis thysanodes thysanodes* infected with the rabies virus, but as with other bats, the incidence of this is likely very low and poses minimal threat to humans (Constantine 1979, Constantine et al. 1979) and no threat to the persistence of the species. However, the perception of bats as deadly vectors of rabies has greatly harmed their image and resulted in public desire to exterminate bats. Bat Conservation International provides a concise account of the bat-rabies connection on its website (<http://www.batcon.org/>), from which much of the following information was derived. Historically, most rabies transmission to humans occurred in domestic animals (e.g., cats and dogs), but following widespread pet vaccination programs, wild animals now represent the bulk of animal rabies cases. Wild animals accounted for about 93 percent of animal rabies cases reported to the Centers for Disease Control in 2001, of which 37.2 percent were raccoons, 30.7 percent skunks, 17.2 percent bats, 5.9 percent foxes, and 0.7 percent other wild animals (Krebs et al 2001), but neither the total number and type of animals turned in nor the methods for their collection were reported. The apparently large proportion of bats in this list may be partially due to an increase in the prevalence of bats being turned in to

disease professionals (Wadsworth Center 2000). Some state-level reports suggest that bats turned into health departments have a lower incidence of rabies infection (often <10 percent of cases), suggesting that the prevalence among the entire wild population is smaller still, perhaps on the order of 0.5 to 1.0 percent (Caire 1998, Wadsworth Center 2000, Wilkerson 2001, South Dakota Bat Working Group 2004). Further, bats rarely transmit fatal rabies infections to humans, as evidenced by the fact that rabies viruses attributed to bats that commonly live in buildings have only been associated with eight human fatalities in all of U.S. history. The most common bat in Region 2 (little brown bat, *M. lucifugus*) has never been documented transferring rabies to humans. Only a bite from an infected bat that breaks the skin can transmit the rabies virus; the virus has not been isolated from bat blood, urine, or feces, and there is no evidence of air-borne transmission in buildings. Thus, the only way for someone to get rabies from a bat is to disturb an evidently sick bat to the point that it inflicts a severe bite, and even then only a small portion of noticeably sick bats actually have rabies. Since normal, healthy bats will usually not allow themselves to be contacted by humans (unless they are in a state of torpor during roosting), virtually all risk of exposure can be eliminated by not handling live bats that allow such contact. If frequent interaction with live bats is a regular occurrence, a highly effective and painless vaccine is available that further reduces risk of transmission. Primary care doctors or public health officials can usually order and administer this vaccine.

Symbiotic and mutualistic interactions

There are no documented symbiotic or mutualistic interactions between *Myotis thysanodes* and non-Chiropteran species. However, *M. thysanodes* have been found roosting with many other species of bats (O'Farrell and Studier 1980), and it is possible that some thermoregulatory and anti-predation advantage is gained from this behavior.

Many bats have a commensal relationship with beaver (*Castor canadensis*), since beaver create small bodies of open water from which bats can drink. Further, beaver ponds promote vegetative growth around their edges and may alter local insect abundance.

Envirogram

Andrewartha and Birch (1984) outline a “Theory of Environment” that seeks to organize the ecology of a species into a coherent and logically connected web of factors that influence its ability to survive and

reproduce. The heart of this endeavor is the envirogram, which orders these factors in a hierarchical dendrogram. The main stem of this dendrogram is comprised of a “centrum” of components that act directly on the species under consideration. From this centrum are branches that “trace pathways from distal causes in the web to proximate causes in the centrum.”

Figure 9 presents an envirogram we have developed for *Myotis thysanodes*. It is a useful heuristic tool to conceptualize how various factors might affect *M. thysanodes*, but it must be duly noted that this is not the last word in what is important to this bat's survival and reproduction. It is largely a hypothetical effort that may vary depending on the authors, their objectives, and their knowledge. As Andrewartha and Birch clearly state, “the detail of the structure scarcely matters; it is bound to vary as each operator pieces the story together in his own way.” More importantly they state the following:

If here and there we seem to have been to preoccupied with the attempt to place a component of environment in its proper category, we would not want to give the impression that classification is an end in itself. The model should work better if we can be consistent in identifying the components of the environment, but the chief aim remains to present a general model of how the environment works, hoping that it might point to the most effective questions to be asked at each stage of an investigation.

With this in mind, the attached envirogram should be viewed as our attempt to model the environment of *Myotis thysanodes*. It highlights some key linkages for future study, but by no means does it define this environment.

CONSERVATION AND MANAGEMENT OF THE SPECIES IN REGION 2

Extrinsic Threats

Roost disturbance

Roost disturbance, as defined herein, encompasses all factors affecting bat roosts up to and including those that lead to the loss or destruction of entire roosts. Roost destruction is the most severe and evident form of disturbance and has been caused at a large scale by anthropogenic activities. Bat conservation experts

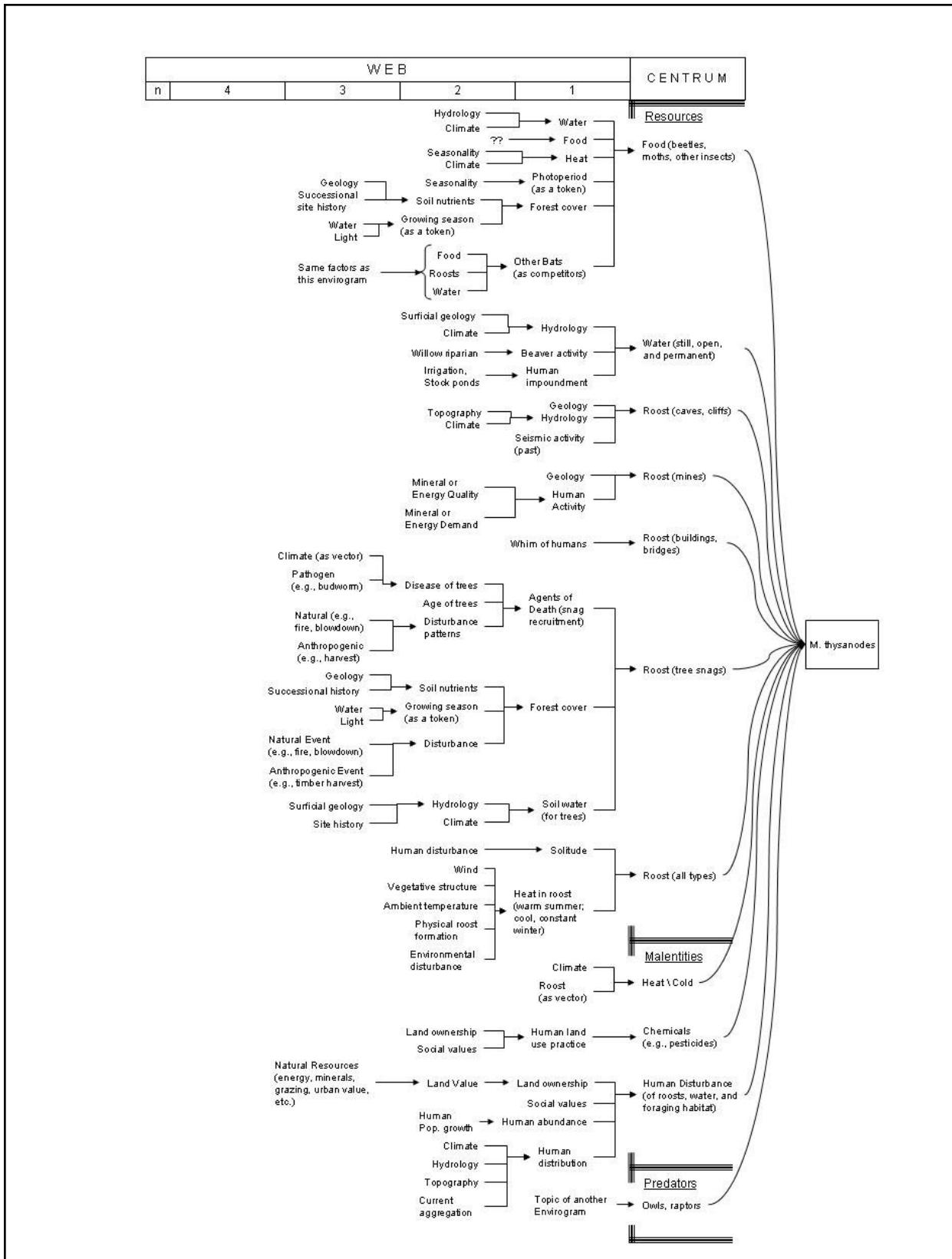


Figure 9. Envirogram of the ecological web surrounding *Myotis thysanodes*. Detailed explanation of envirograms can be found in Andrewartha and Birch (1984).

suggest that a loss of natural roosts has occurred throughout the United States due to our land resource management practices, including, but not limited to, removal of large diameter, cavity-forming trees from the landscape, human activity in caves, closure of mines without consideration of bat access, and uninformed building and bridge modification (Pierson et al. 1995, Altenbach et al. 2002, Ellison et al. 2004). Removal of riparian vegetation and mature forest through commercial and residential development, agriculture, and logging destroys possible tree roosts, foraging areas, and travel routes (Barclay and Brigham 1998). Silvicultural practices appear to favor monotypic stands, short rotation times, and selective tree harvest leaving minimal roosting habitat for tree-roosting species (Pierson 1998, South Dakota Bat Working Group 2004). However, roost loss can be caused by far more subtle events, such as modification of the canopy surrounding roost snags that changes cavity thermal regimes by altering exposure to sunlight. Bats choose their roosts based on a combination of specific factors (see Habitat section), and any modification of one or more of those factors has the potential to disrupt roosting bats. *Myotis thysanodes* is just as susceptible to loss of roosts as other bats, and this should be considered a primary threat impeding its conservation. Fortunately, it is also the threat that resource managers are best able to control.

Beyond modifying the physical roost environment, human intrusion into bat roosts has been shown to cause abandonment of roost sites by many species (Brown and Berry 1991, Wilson and Ruff 1999); however, documentation of abandonment by *Myotis thysanodes* in particular is scarce and largely anecdotal (P. Brown personal communication 2003, E. Pierson personal communication 2003). Regardless, this species appears to be extremely sensitive to disturbance at roost sites and to human handling, more so than other species of *Myotis* (like the Yuma myotis).

Often, intrusive disturbance is intentional and people actively seek to exterminate bats, usually due to uninformed or misinformed perceptions regarding the nature of bats, particularly with relation to disease such as rabies. This is especially true of bats roosting in human structures, such as attics and barns, where they more frequently come into contact with people. However, it also occurs in other areas where bats congregate, most notably caves and mines.

A less evident, but no less destructive, form of disturbance is recreational entry into roosting structures. It has been clearly documented that several bat species,

including *Myotis thysanodes*, are sensitive to the presence of humans while they are roosting and may abandon roosts if sufficiently disturbed, particularly during critical times around parturition (O'Farrell and Studier 1973). This is especially true of caves and mines, which can receive heavy human traffic and often bring humans in close contact with bats due to the confined nature of the environment.

Non-roost habitat alteration

Any habitat alteration that changes components described in the Habitat section has the potential to negatively impact *Myotis thysanodes* populations. Given the complex nature of bat habitat use, adverse alteration can result from a wide variety of sources. A short and very incomplete list of examples might include timber harvest, vegetative conversion, livestock grazing, suburban expansion, water development, avalanche blasting, road construction, toxic waste impoundment, pesticide use, wildland fires, stream channelization, flood control, recreational activities, and invasive vegetation. Unfortunately, there are few clear-cut answers regarding how these and a myriad of other human activities affect *M. thysanodes*. Land management actions must therefore be evaluated on a case-specific basis. The bottom line is not the particular action in question but how that action modifies the habitat available to *M. thysanodes* populations. For example, water impoundments can be negative (flood roost sites, change insect fauna, change vegetation), neutral, or positive (increase available water, increase insect abundance) for local bats. Biologists and land managers must use critical judgment in considering how an action under consideration might change the suitability of the *M. thysanodes* environment. For example, it is less important to realize that livestock grazing might affect bats than it is to know what bats need and implicitly understand how grazing might change their environment. We have, therefore, focused this discussion on effects rather than specific actions and strongly encourage the reader to think critically about how a proposed action or course of actions might affect *M. thysanodes*. Following are examples of how habitat changes might negatively impact bats via alteration of key habitat features.

Any change in habitat that modifies microclimate in and near roosts (e.g., airflow and/or thermal regime) can substantially impact bats (Tuttle and Stevenson 1977, Richter et al. 1993). Daily energy budgets of bats are in delicate balance, and anything that alters this balance can result in lowered fecundity, mortality, or roost abandonment. For instance, physical

modification of cave and mine entrances, including substantial vegetative alterations outside the entrances, or improperly constructed gates, can alter thermal and airflow characteristics of roosts, resulting in population declines. This also applies to non-permanent roosts such as tree snags. Modification of the forest around snags can alter solar and wind exposure, thereby making an otherwise suitable roost unfit for bat occupancy because it is too hot or cold to allow bats to effectively thermoregulate.

As suggested above, in some areas, particularly where primary roost structures are tree snags, *Myotis thysanodes* selects areas of high roost density rather than specific roost sites *per se* (Cryan 1997, Lewis 1995). Therefore, a reduction of old forest and snag density can have negative impacts on local populations, and there is some evidence that such impacts may increase with decreasing elevation (Grindal 1995, Cryan 1997).

The importance of open-water impoundments in suitable habitat and proximate to roost sites has been clearly stated (see Habitat section). Factors that alter water flow or persistence (e.g., stream channelization, irrigation or municipal diversions, drought, beaver activity) can greatly impact bat distribution and, perhaps more importantly, alter critical daily energy balances of bats by shifting their foraging patterns.

All North American bats occurring in Region 2 feed on insects, and insects in turn depend on both aquatic and terrestrial vegetation. So, it is quite possible that reduced prey availability may result from reduced species diversity of plants (South Dakota Bat Working Group 2004) caused by, for example, invasive weeds and/or over-grazing of riparian areas by livestock. Removal of trees can reduce potential foraging areas for bats, as prey appears to concentrate near treetops and along forested edges and water courses (South Dakota Bat Working Group 2004). Pesticides used to treat mosquitoes educate not only the targeted group but may also kill other insects.

Since *Myotis thysanodes* optimally requires a habitat mosaic with several key features in proximity (see Landscape context section above), disturbances that act to homogenize the landscape at the scale of typical bat foraging areas (see Area requirements section above), will likely lead to a reduction in suitable habitat. However, increased forest fragmentation also has been shown to decrease the occurrence of some bats (Ekman and de Jong 1996, Walsh and Harris 1996), so caution should be used when managing complex landscapes. There is likely an optimal range of habitat

proportions and configurations (e.g., forest and roosting habitat versus open habitat versus water), but there are no quantitative guidelines available to managers. We might suggest that local studies be done to quantify habitat configuration in areas supporting strong *M. thysanodes* populations and be used as rough guides on which to base future plans.

The impact of fire on bat populations has not received sufficient study. However, since bats require specific environmental components (i.e., roost structure, water source, foraging habitat), it can be assumed that to the extent fire reduces one or more of these components, it will have a negative impact on local bat populations. Depending on the nature of the fire, however, it may increase bat habitat suitability. For example, snag density and habitat heterogeneity may increase in a patchily burned timber stand. It should be noted that these positive effects are not likely to become beneficial until several years after the fire incident, when regeneration progresses, while negative effects are immediate.

Chemicals

No studies have been done specifically addressing the effects of chemical pollutants, most notably insecticides, on *Myotis thysanodes*. Moreover, very little research has investigated impacts of these chemicals on any North American bat species. However, it is likely that such chemical pollutants could be responsible for bat declines in some areas (Rainey and Pierson 1996). There are two basic mechanisms by which these chemicals most impact bats: toxic impoundments and pesticide application to crops and/or water bodies. More information on general contaminant toxicity and remediation can be found through the Environmental Protection Agency (U.S. Environmental Protection Agency 2001, <http://www.epa.gov/pesticides/>).

Chemicals entrained in the water column of impoundments, for example cyanide leach ponds associated with heap-leach gold mining, can result in acute or chronic poisoning of bats (Clark 1991, Ellison et al. 2004). Contaminated sediments often contain even higher concentrations of pollutants than the water column. Insects emerging from the contaminated sediments of impoundments, lakes, or streams can carry elevated levels of toxins in their tissues, which may then be transferred to and bioaccumulate in bats that consume them in the same manner as the pesticides described below (Steingraeber et al. 1994, Kenneth et al. 1998, Clark and Shore 2001). Specific contaminants with demonstrated toxicity to bats

include PCB's, lead, cadmium, blue-green algal toxins, effluent from cyanide extraction gold mines, and impounded sewage (Clark and Shore 2001). Covering contaminated impoundments can reduce access by bats and thus reduce exposure through the water column, but controlling insect use of impoundments is more difficult and often requires the use of pesticides that may have their own impacts (see below).

Pesticides impact bats via two primary mechanisms by significantly reducing the abundance of bat prey and by accumulating in the surviving prey and eventually becoming concentrated in bat tissues through the consumption of contaminated prey. Studies have shown that bats accumulate very high concentrations of organochlorines (e.g., DDT, DDE) and other contaminants in their tissues, often many times above levels bioaccumulated by other taxa, such as birds (Jefferies 1972, Clark and Shore 2001, O'Shea, et al. 2001). In a study downstream from a DDT manufacturing plant "residues in nestling red-wing [black bird] carcasses had declined to trace amounts, averaging 0.28 mg kg⁻¹ DEE with no DDD or DDT detected in birds collected 20 km downstream from the DDT source, whereas juvenile gray bats at this same point contained 34 mg kg⁻¹ DDE, 12 mg kg⁻¹ DDD, and 0.34 mg kg⁻¹ DDT. Furthermore, this contaminant was recognizable in gray bat colonies at least 140 km downriver" (Clark and Shore 2001).

Probable reasons for this elevated rate of bioaccumulation in bats and other factors related to increased bat sensitivity to environmental contaminants are summarized by Clark and Shore (2001):

- ❖ **High metabolic demands:** High metabolic rate associated with small size, flight demand, and greater rates of food intake, increases the rate of intake and potential accumulation of chemicals.
- ❖ **Pronounced fat cycles:** Most bioaccumulation of lipophilic contaminants occurs in fat. Bats risk mobilization of stored contaminants through extreme shifts in fat depletion resulting from migration and/or hibernation. It also suggests that bats are most susceptible to such compounds when fat stores are low, which is most pronounced in the spring, after winter hibernation.

- ❖ **Lactation:** Chemicals tend to concentrate in milk, exposing young to large doses and potentially resulting in reduced fecundity.
- ❖ **Behavior:** Bats forage on insects most heavily in twilight hours, which is when insects are most abundant and when pesticides are often applied to avoid drift; so bats may be prone to direct exposure during application.
- ❖ **Life cycle:** Bats have long life spans, allowing more time for contact with and potential accumulation of contaminants. They also have low reproductive rates, which would restrict the ability of bat populations to rebound from mortality events associated with increased contaminant levels.
- ❖ **Roosting:** Roosting can increase bat exposure to toxins by concentrating bats in small areas, making incidental exposure of large groups more likely. Bats roosting in buildings may be exposed to chemicals used to treat lumber (e.g., fungicides, lindane, dieldrin), some of which have been shown to be quite toxic to bats.

Despite bioaccumulation studies, contaminant-induced mortality and morbidity to the range of chemicals to which bats are commonly exposed have not been well studied, and no studies have been conducted specifically for *Myotis thysanodes*. A summary of mean lethal concentrations in the brain for some chemicals and bat species is provided by Clark and Shore (2001). Well-documented impacts to wild bats from exposure to hazardous substances are rarely available and would in fact be difficult to acquire given the problems associated with observing bats. For instance, lethal insecticide doses for some bat species are above those of laboratory mice, suggesting low susceptibility to environmental application of such chemicals (Clark and Shore 2001). However, it has been shown that doses well below such levels can induce loss of coordination that completely prevents flight and alters energy metabolism (Clark and Shore 2001). In the wild, the proximate cause of death in such cases would likely be predation and, therefore, would not be correctly attributed to toxins. Another example is that total tissue concentrations are not necessarily an indication of the immediate

lethality of contaminants. Lipophilic organochlorines are toxic via impact on the brain of vertebrates, but as noted above these chemicals can be stored in fat. Therefore, even sub-lethal concentrations can accumulate over time, resulting in lethal concentrations when the fat is metabolized, such as during hibernation. Mortality could occur over winter, when nearly all fat is metabolized and not be temporally or spatially proximate to chemical application.

Commensurate with these difficulties, very few population-level impact studies have been undertaken (see Clark and Shore 2001 for summary data). Of these, two studies documented substantial declines in local bat populations resulting from organochlorine application (aldrin and DDT). Population-level effects have occurred as a result of intentional or incidental application of acutely toxic pesticides to bats in their roosts, causing direct adult mortality; and from application of pesticides (e.g., lindane, dieldrin, PCP) to roost structures, the residues of which caused increased adult mortality and reduction of successful breeding for years afterward.

Wind energy

The impact of wind-energy turbines on bats has received increasing attention because several studies have demonstrated bat mortality due to collision with turbine blades (Osborn et al. 1998, Keeley et al. 2001, Johnson et al. 2003). Many species of bats have been found killed at these turbines, but in most cases mortality is heavily skewed toward Lasiurine species (e.g., hoary bats and red bats), which sometimes represent more than 70 percent of recorded mortalities (Johnson et al. 2003, Williams 2004). Bat species found killed at lower concentrations include silver-haired bats, eastern pipistrelles, little brown bats, and big brown bats. *Myotis thysanodes* mortality at these sites has not been confirmed. Although this may be good news for *M. thysanodes* conservation, it does not necessarily mean that there is no danger to *M. thysanodes*, since it may be that the few wind-power facilities studied to date are coincidentally in areas not frequented by this species. Even though such facilities may not prove to be detrimental to *M. thysanodes*, further research may demonstrate danger to other bat species. The Western Bat Working Group has established a committee to evaluate wind farm issues and provide recommendations, but it has made little progress to date. Therefore, it is recommended that resource managers in Region 2 dealing with wind-power issues keep in touch

with their local bat working groups regarding the latest developments in this field.

Biological Conservation Status

Abundance and abundance trends

Myotis thysanodes appear to be relatively rare rangewide, but trends in abundance are largely unknown. In addition to the numerous difficulties in monitoring bat populations (see Survey, inventory, and Monitoring section below), the fact that *M. thysanodes* are relatively rare makes trend estimation particularly problematic. The few long-term studies of abundance, which looked at a variety of bats, occurred in New Mexico in the 1960s and 1970s. They demonstrated both positive and negative fluctuations over the course of 5 and 10 years, producing largely unclear trends, possibly reflecting a net increase (Jones and Suttkus 1972, Easterla 1973). Potentially confounding estimates of population size, particularly those based on once or twice-annual visits, are monthly changes in local abundance (Jones 1966) with shifts in roosting over the course of the summer (Lewis 1995, Cryan 1997).

The Arizona Game and Fish Department (1997) characterizes *Myotis thysanodes* populations in Arizona as apparently stable based on limited survey data. The Nevada Bat Conservation Plan (Altenbach et al. 2002) states that Nevada records are relatively few but suggest an apparent increase in numbers or area occupied by the species over the last 20 years. This may, however, be an artifact of increased survey effort and better techniques. Although no trends in abundance were evident, Ramsey (1998) reported that *M. thysanodes* was recorded in a broader range of habitats in the Gila National Forest of New Mexico than previously reported, which may have had as much to do with structural changes in the environment and water sources than with habitat type *per se*.

Museum records suggest that *Myotis thysanodes* is widely distributed across California, although it is always one of the rarest species in netting and night roost surveys in a number of localities (Pierson et al. 1996). The limited data available suggest serious population declines. Not only have historic maternity colonies disappeared, but those remaining appear to contain significantly fewer animals (Pierson 1998).

There is insufficient data to estimate abundance trends for Region 2. Based on the information presented

above, however, it appears that there may be a national declining trend in roughly similar habitats throughout the range of *Myotis thysanodes*. Therefore, until local and regional studies are conducted, Region 2 managers should assume that the national declining trend is likely being played on regional forests as well.

Distribution trends

Bats have received increased attention over the last decade, resulting in increased survey effort, improved researcher bat identification skills, and expanded knowledge of peripherally occupied areas and connectivity among bat populations for many bat species. Despite this, the overall known distribution of *Myotis thysanodes* does not appear to have changed greatly over time (this assessment, Jones and Genoways 1967, Barbour and Davis 1969, O'Farrell and Studier 1980, Wilson and Ruff 1999). However, bat surveys are still largely opportunistic, and very few survey sites have been revisited with any degree of regularity, so geographic trends in presence are largely unknown. Furthermore, the proportion of the overall range of *M. thysanodes* that is actually occupied is unknown for large areas. Virtually no information is available for any populations in Mexico.

Although the total continental distribution has not drastically changed, it is likely that local and, possibly, regional populations have fluctuated and perhaps contracted, becoming more isolated in recent decades. This appears to be true for Wyoming (**Figure 2b**). There have been no recent sightings of *Myotis thysanodes* in the northwestern portion of the state, despite relatively recent surveys (Wyoming Natural Diversity Database, Laramie, Wyoming unpublished data).

Habitat trends

Information on habitat trends, particularly for Region 2, is not readily available. As suggested in previous sections, one must consider trends in roosting habitat, foraging habitat, and water sources together. Estimating trends in the area of suitable habitat for each of these three categories is in itself a difficult task. Even more problematic is estimating trend in the juxtaposition of all three habitat components at both the fairly fine spatial scale of individual bat colonies (i.e., on the order of 100's of hectares) and at the landscape scale. The discussion in the following paragraphs is therefore largely expert opinion derived from reasoned extrapolations of existing data.

Cliff roosts can be destroyed by dam and road construction in canyons and impacted by rock climbing activity. Large cliff complexes often draw tourists, often leading to recreational development and the associated negative impacts to surrounding habitat. The extent of such alteration and disturbance is undocumented. Nonetheless, we hypothesize that available cliff surface has decreased somewhat (nationwide and in Region 2) since the mid 20th century due to reservoir construction and establishment of high-traffic tourist zones around some cliff features. On the other hand, reservoirs may increase foraging area for bats and make formerly unsuitable cliffs available to bats, so the net effect is unclear. In any case, such development has slowed markedly in the past few decades. Despite such losses, relative to other roost structures (especially caves and mines), cliff roosting habitat has probably not experienced great declines in abundance. This is due largely to the relative permanence of cliffs and the difficulty of access by humans.

Trends in forest roosting habitat (i.e., aggregations of large, old snags in late-successional forest) are also fairly unclear but may be decreasing. Certainly, such habitat structure is substantially reduced from pre-settlement conditions. A recent analysis of the historic range of variability (HRV) for forest stand dynamics in the Bighorn National Forest, Wyoming (Romme 2002, unpublished data) suggested that prior to European settlement the Bighorn landscape might have contained 15 to 30 percent old-growth forests. Rough estimates of current old growth are more on the order of 10 to 15 percent (J. Warder personal communication 2003). The Black Hills National Forest is predominantly ponderosa pine (~ 85 percent), which may naturally constitute good habitat for *Myotis thysanodes*, but the proportion of the Black Hills currently in old growth condition is small (~ 2 percent) and decreasing (unpublished data provided by Black Hills National Forest). Likewise, an HRV assessment for Pike and San Isabel National Forests in Colorado (Veblen et al 2000) concluded that timber harvesting profoundly altered forest structure of the Colorado Front Range, with the greatest effect on old-growth montane forests. Forest data indicate that no ponderosa pine stands and just one Douglas-fir stand over 200 years old are found in these montane forests.

If this condition and downward trend holds true in other forests, the available forest roosting habitat for *Myotis thysanodes* has decreased over the last century by a potentially large amount. Veblen et al. (2000) state "The removal of the largest and oldest trees is

generally reflected in the late 20th century age structures of ponderosa pine stands which throughout the West often have relatively few trees older than 100 to 200 years...". Regenerated logged forests also tend to lack the abundant snag component found in unlogged late-successional forests. Although these trends in timber harvesting have abated on many regional forests, the Healthy Forest initiative (President of the United States 2002) has created a new emphasis on reducing fuel loads in forests, including older stands. As larger snags and other fuels are removed from older forests, there likely will be a continued loss of habitat capability for *M. thysanodes*.

Suitable cave roosting habitat already is limited in Region 2 and has likely decreased over the last century due to human disturbance of cave systems (South Dakota Bat Working Group 2004). Large cave complexes are particularly vulnerable to such disturbance because they attract tourists and "cavers" and have often become part of national or state parks. In recent decades, however, awareness of the importance of caves to bats has increased, and actions (such as seasonally limiting access to caves) are slowly being taken to protect key cave complexes from undue disturbance. If this trend continues and is supported by land management agencies, we expect the downward trend in cave roosting habitat to stabilize in the next decade. The availability of abandoned underground mines may somewhat mitigate the loss of cave habitat, but there are several reasons why this is not fully compensating. First, some mines are not suitable for roosting bats. It has been estimated that 80 percent of abandoned mines may be used by bats, and only 10 percent receive substantial use (P. Brown personal communication 2003). Second, many mines have been closed or are planned to be closed for human hazard abatement without regard to bat use. Third, locations of mines are not necessarily conducive to bat colonization due to the lack of proximal, suitable foraging and drinking habitat. Despite these drawbacks, abandoned mines can have a significant positive impact on local bat populations and should be carefully considered in management strategies (Tuttle and Taylor 1994, Altenbach and Pierson 1995, Riddle 1995).

Building roosts have likely become increasingly important to some bat species as natural roost sites become more limiting (M. Austin personal communication 2004). However, the trend in *available* human structures suitable for use by roosting bats is unclear. Public persecution of bats, due largely to a misunderstanding of their nature and fear of disease such as rabies has probably caused a decrease in

available building roosts during most of the 20th century, despite nearly continuous growth in construction. This trend may have abated somewhat in the last decade, as extensive efforts to educate the public about bats and ecologically sound methods to deal with "pest bats" have become established (French et al. 2002). Abandoned buildings in forested areas of northern Wyoming are often used by roosting bats, but several public land efforts are underway to destroy these buildings due to public safety concerns or to restore them as interpretive historic sites, both of which typically result in loss of roosting habitat (author, unpublished data). We hypothesize that the overall trend in building roosts in Region 2 is probably slightly negative, but that this can be stabilized by increasing public awareness of the benefit of bats, eliminating bat extermination policies, and conducting bat-friendly restoration practices (for more information, contact Bat Conservation International: www.batcon.org).

Trends in available foraging and water habitat are much harder to estimate than trends in roosts. Not only are such areas more diffuse in the landscape, but the foraging habits of most bats are not nearly as well understood. For instance, it is not known exactly what elements influence habitat selection by *Myotis thysanodes*, although based on the variety of forest types occupied, it appears that vegetative structure and stand age may play more important roles than plant species composition. Still, an array of human activities likely continues to erode bat habitat. For instance, the application of chemical treatments, such as pesticides and herbicides, can make otherwise good foraging habitat unsuitable, either through direct poisoning of bats or reduction of the insect prey base. Drought events, such as that currently occurring in much of the Rocky Mountains, can reduce the number or areal extent of wetlands, as can declining trends in beaver impoundments. Water diversions and channelization of streams continue to adversely affect wetlands and result in the narrowing and decline of riparian corridors important for bat foraging.

Intrinsic vulnerability

Bats populations in general, and *Myotis thysanodes* in particular, are vulnerable to extirpation by virtue of their life history. An interagency expert evaluation panel considered *M. thysanodes* to be more vulnerable to alteration of mature forest ecosystems than most bat species because it depends on old-growth conditions (i.e., forests with abundant, large snags suitable for roosting; see Habitat section), is rare, occurs in a restricted elevation zone, and has

strong site fidelity (Forest Ecosystem Management Assessment Team 1993). We can add sensitivity to roost disturbance, restrictive hibernation requirements, and low reproductive capacity to this list.

Myotis thysanodes are widespread, like many bat species, and therefore tend to be overlooked in conservation efforts that often focus inordinate value on distribution extent as a criterion for sensitivity, with little consideration of connected factors such as rarity and site fidelity (Pierson 1998). Although their range is large, they are rare and patchily distributed within that range. Moreover, *M. thysanodes* require a specific and restrictive combination of habitat characteristics. If any part of this system is disturbed, it could result in local extirpation. Further, site fidelity has been demonstrated for *M. thysanodes* both at the stand and roost scales (Forest Ecosystem Management Assessment Team 1993, Cryan 1997, Weller and Zabel 2001). Maternal *M. thysanodes*, in particular, show high preference for specific roost caves to which they return over the course of a summer and from one summer to the next (Cockrum et al. 1996). A similar preference is shown for specific watering places (Cockrum et al. 1996). Since isolated populations of species with high site fidelity have low recolonization potential, local disturbances can have disproportionately greater effects on species distribution and metapopulation viability.

While in the roost, *Myotis thysanodes* appear easily disturbed by human presence, particularly in maternity colonies when females are near parturition (Studier and O'Farrell 1973). Disturbance at hibernacula could be even more detrimental for several reasons. First, the margin by which bats survive winter hibernation is often very small, so any event that causes them to rouse from torpor can expend energy sufficient to cause over-winter mortality. Second, due to the relative scarcity of suitable hibernacula, bats from wide areas tend to concentrate at only a few sites. The loss, therefore, of even one such site can have potentially far-reaching consequences (Pierson 1998).

Finally, the low reproductive rate of *Myotis thysanodes* (see the above discussion on breeding) means that populations cannot easily recover after crashes.

Management of the Species in Region 2

Myotis thysanodes conservation is important throughout the Rocky Mountains. However, the Black Hills National Forest is one obvious focal point for *M. thysanodes* conservation, because it contains a large portion of the locally endemic *M. t.*

pahasapensis subspecies (see Taxonomy section), which is, questionably, isolated from the populations in the main range (see Distribution section). Further, due to aggressive timber harvesting in the Black Hills that has significantly reduced old-growth forest (see Habitat trends section) and widespread recreational activity, it appears evident that land managers in the Black Hills must be particularly aware of *M. thysanodes* conservation in future planning.

Conservation elements

No studies have explicitly investigated the implications of environmental change on *Myotis thysanodes*. However, studies conducted on the effects of human actions on bat communities and the similarity of those communities to *M. thysanodes* populations allow for reasoned inference to *M. thysanodes*. Five main areas of conservation activity are needed for *M. thysanodes* and many other bat species in Region 2. Specific management approaches that have been proposed to address these needs are provided in the following section on Tools and Practices. A major message to take from this discussion is that land managers must consider a suite of factors *together* when trying to conserve *M. thysanodes* and other bats.

1. **Protection of roost sites:** Bats are very sensitive at roosts, and any disturbance to a roost site (e.g., cave, cliff, building, snag; see Roost section) can potentially extirpate bats from that site or even the locale. This is particularly true if a disturbance is long lasting, is intense, or results in a long regeneration time. Loss and destruction of roosts are the most extreme cases of disturbance and should be avoided at all costs. Protection of maternity roosts and hibernacula are particularly important, given their biological value to the bats and their relative scarcity in the environment. Where tree roosting is prevalent, roost protection requires more planning, since the local abundance, structural characteristics, microclimate, and spatial distribution of current and future snags must be considered.
2. **Protection of foraging areas:** In Region 2 *Myotis thysanodes* forage in a heterogeneous mix of conifer forest (often, but not limited to, ponderosa pine and pinyon-juniper) and shrubland/grassland with ample water sources (see Habitat section) and abundant prey (insects). Given the range of specific

vegetation types used by this species (see Habitat section), it is likely that the landscape in which they occur is at least as important as the vegetation itself (see below and Landscape context section). It can be assumed that any decrease in insect abundance, particularly of beetles and moths, will have a direct negative effect on *M. thysanodes*, although the “critical level” below which insect numbers must fall before significant declines in bat use are likely is unknown. This is further complicated by the fact that the community of insects at a site depends on vegetation composition and structure occurring at that site (both aquatic and upland). The corresponding response relationship of insect populations to changes in vegetation (e.g., through grazing or timber harvest) is unknown. Similarly, we do not know the exact amount of cover preferred by foraging, forest-dwelling bats. We can be fairly certain that elimination of cover altogether (e.g., in large clearcuts) will have a negative impact on clutter-adapted bats like *M. thysanodes*. However, it may also create suitable edge habitat, which is preferred by some species (see References in Grindal and Brigham 1999).

3. **Protection of water sources:** Open water sources may be necessary for bats to drink on the wing and as insect breeding sites. Three aspects of water sources must be maintained: presence, faunal character, and water quality. If wetlands are eliminated (e.g., by draining, drought, water diversion, shifts in the water table), local bat populations are likely to suffer, depending on the availability of other nearby water sources. Further, if they are modified (e.g., through a change in water regime or flora due to timber harvest, damming, diversions, or cattle grazing) to such an extent that their associated insect fauna changes, it could adversely affect the bat population. Water quality also must be maintained, because water contamination (see Chemicals in Extrinsic Threats section) can impact bats both directly and indirectly.
4. **Maintenance of a landscape mosaic:** Bats select roosts, foraging areas, and water sources for different qualities, and it is not sufficient to protect these three elements in isolation. *Myotis thysanodes* require a

landscape that contains all three habitat elements in geographic proximity (e.g., less than several km) in order for bats to efficiently use them. The extent to which roosting and foraging areas are geographically proximate contributes to the capability of habitat to support viable bat populations. Because of the delicate energy balance of bats, they can be impacted greatly by increases in required flight time between roosts and foraging and water sites. Increased commuting time reduces time spent foraging, while increasing energetic demands (Studier and O’Farrell 1980). Thus, ideal areas for *M. thysanodes* (and many other bats) will contain a mosaic of foraging habitat, still water sources, and roost structures that are proximate to each other over a large enough area to accommodate shifts in local prey abundance.

5. **Elimination of exposure to toxic chemicals:** Man-made water sources are often used by bats, so preventing bat use of toxic impoundments, such as cyanide ponds, oil reserve pits, and wastewater facilities is important (Rainey and Pierson 1996, Pierson et al. 1999). Also, it is necessary to investigate the impacts of modern pesticides on bat populations, both through direct poisoning effects and through reduction of prey, and to eliminate the use of those pesticides that may be detrimental.

Tools and practices

Describing all the tools and practices necessary to conserve bats, including all their associated assumptions, caveats, and interactions, is beyond the scope of this assessment. The following sections present a selection of information that we believe is particularly pertinent to *Myotis thysanodes* but does not represent a comprehensive picture of what should be considered in managing for the species. We encourage biologists and managers in Region 2 to use this assessment as a starting point, then to consult guidelines presented in their relevant state’s bat conservation plan (e.g., Pierson et al. 1999, Altenbach et al. 2002, Ellison et al. 2004, Hinman and Snow 2003, South Dakota Bat Working Group 2004). Work closely with state bat working groups (<http://www.wbwg.org/>) to make sure plans are interpreted and applied correctly. Given the unique ecology of bats, it is essential to consult bat biologists, particularly those that are locally knowledgeable, in management planning.

Acting on conservation elements

The following are some basic management guidelines tied to each of the above noted conservation activities that have been suggested for conservation of *Myotis thysanodes* and similar bats. Most of the buffers and times noted are expert suggestions and are not based on specific scientific studies. Be aware that they may not in fact be adequate in all cases and may vary with different habitats and types of disturbance. Therefore, numbers presented should be viewed as minimum recommendations. Also, since most of these guidelines are fairly recent, data on their effectiveness are not yet available. Therefore it is critical that any such actions taken incorporate an initial inventory and thorough, long-term, post-treatment monitoring of the affected bat populations in order to determine management efficacy.

1. **Protection of roost sites:** *General* – Areas of timber management (e.g., prescribed burning, thinning, harvesting) should be thoroughly searched for roosts. First, create a search image for suitable habitat, as described in the above sections, for the analysis area. If suitable habitat appears to be present, consider placing acoustic detectors to check for bat activity in the area. If there is suitable habitat and bat activity, then roosts are likely present in the vicinity. Sometimes, one is able to actually see or hear a bat in a roost, but often they are hidden in small spaces away from easy observation. Signs that might indicate bat presence include the accumulation of guano or insect wings or carapaces. Bat guano generally looks like rodent scat, but unlike most rodent scat it will crumble easily, and rather than being composed of plant material, it will consist of insect exoskeletons (i.e., it will glitter slightly in light when it is crumbled). Realize that roosts, other than those in caves or buildings, are very difficult to identify without careful searches, and even then the only way to find them may be with radio-collared bats captured at foraging areas and tracked back to roost sites. Just because one does not find a tree roost does not mean that roosts are not present. When habitat and activity suggest roosts but none can be found, we recommend seeking the advice of bat experts.

Tree roosts: Where there are tree-based roost complexes, roost trees should not be

modified, and day roost habitat should be managed to maintain groups of large, tall snags in early to medium stages of decay. To maintain a temporally continuous population of roost snags, it has been suggested that a minimum of eight large snags per acre be retained during timber operations, especially in riparian areas and areas with other known bat roosts (South Dakota Bat Working Group 2004). However, if studies in California are applicable in Region 2, regular pockets containing over 80 large snags per hectare could be necessary to support *Myotis thysanodes* populations (Weller and Zabel 2001). This high number is echoed by other studies that suggest, due to use of multiple snags by maternity colonies and the short longevity of bark on snags, bats require higher early-decay snag densities than birds (Rabe et al. 1998 as cited in Ellison et al. 2004). Further, since roosts are generally in less-dense microsites in otherwise contiguous mature forest (see Habitat section), snags left in clearcuts will not provide habitat for bats as it does for some cavity nesting birds (Vonhoff and Barclay 1997). Also, the abundance and spatial distribution of roost snags on the landscape are important. Moreover, if local populations are to persist, the maintenance of appropriate snag densities in perpetuity is necessary. Thus, forest managers need to consider snag recruitment, which effectively means retaining green trees of various sizes to serve as future snags (Pierson 1998, South Dakota Bat Working Group 2004). Policies or logging practices that permit intensive logging of old growth and selective removal of dead and dying trees (e.g., Healthy Forest Initiative [President of the United States 2002]) are likely to be detrimental to the maintenance of such a landscape.

Caves, mines, buildings: The first step in preserving other roost structures (e.g., caves, mines, buildings) is to evaluate and prioritize them. Ideas to conserve high priority structures follow.

- a) Caves, mines, and buildings that contain hibernacula should be closed to public access between at least November 1 and April 1 each year, and maternity colony sites should be closed from at least April

1 to October 1, in order to minimize lethal disturbance to roosts (Altenbach et al. 2002). For caves and mines, this usually means installing bat-friendly gates (e.g., Vories and Throgmorton 2002), and for buildings installing locks and/or fences are used to prevent human disturbance. Clearly visible interpretive signs at caves and mines that do not block air flow can educate the public of the reasons for the action and hopefully avoid vandalism by uninformed parties. Since each site is unique, biologists should consult with state bat working groups and/or Bat Conservation International to develop site-specific plans for gating caves and mines in a manner that will cause the least amount of disturbance to the bats.

- b) For cave, mine, and building maternity roosts and hibernacula, no prescribed burning or major forest alteration (e.g., clearcutting) should be conducted within a 0.25 mile radius of the roost. Further, no more than half of a 1.5 mile radius buffer around the roost should be subject to such action in a given decade (Pierson et al. 1999).
- c) When forest management actions occur near roosts, they should be conducted only when the roost is unoccupied or else not within a 0.25 mile buffer of the roost. Whenever activities occur within this buffer zone, even when the roost is unoccupied, a minimum intact forest buffer of 500 feet should be left around all roost entrances, so as not to alter air flow and thermal regimes in the roost. Similarly, roost entrances should not be visible from a road or trail, to minimize human visitation (Pierson et al. 1999). The Nevada Bat Working Group suggests providing a 10 km radius buffer zone around maternity roosts in pinyon-juniper and subalpine conifer habitats to protect foraging sites near those roosts (Altenbach et al. 2002). These buffer zones should receive high priority for fire suppression in fire management plans, and timber management should be minimized, particularly when the roost is occupied. Additionally, there should be a smaller buffer of 2.5 km radius around

known roosts in which no burning or vegetative alteration should take place.

- d) Once protective action is taken on any structure, significant hibernacula and maternity roosts should be monitored (especially gated mines and caves) to determine management effects.
- 2. **Protection of foraging areas:** Since it is hard to clearly define bat foraging areas, it is similarly hard to manage for them. Forest edges and wetlands occurring within the scale of bat home ranges (e.g., within 40 ha and no more than 1 to 4 km apart from each other or roost sites) are important components of good foraging habitat. For woodland foraging species, such as *Myotis thysanodes*, at least 90 percent of existing canopy should be conserved within those watersheds where the bats are likely to occur, in order to provide sufficient foraging habitat (Altenbach et al. 2002). South Dakota Bat Working Group (2004) also recommends leaving at least 25 to 30 percent of salvage logging and fuelwood cutting areas as patches of land with large trees (dead or alive) representative of the entire stand for bat habitat. Agile forest bats similar to *M. thysanodes* do not appear to use clearcuts (as some larger bats do) nor do they use young forest stands (e.g., regenerating clearcuts) (Erickson and West 1996, Grindal 1996). Selective harvest strategies appear to reduce the activity of these bats, presumably because they reduce available roost sites (i.e., large snags are removed) and do not provide better foraging habitat in the form of clutter-free edges (Bohn 1999). The impacts of other harvest types have not been studied, and this is an important information need (see Information Needs section). However, without additional data, we can hypothesize that small patch cuts that provide increased edge habitat while maintaining large stands of mature, snag-rich forest might be less intrusive to forest dwelling bats. The best number, placement, and scale of such cuts depend on a variety of factors, some of which are discussed below in Maintenance of a landscape mosaic.
- 3. **Protection of water sources:** Land managers should minimally strive to

maintain wetland habitats within a 4 km (2 mile) radius of maternity roosts and other roost complexes to achieve year-round water and native vegetative structure. However, given the uncertainty surrounding bat habitat use, land managers should consider expanding this radius to a distance of a 16 km, as per recommendations from Pierson et al. (1999) and Ellison et al. (2004). Riparian areas should be managed to maintain woody vegetation along streams and lakes and to provide large woody material in those water bodies that promotes use by emergent insects. In general, managers should attempt to retain natural stream hydrology and geomorphology (e.g., bends and shallows) and to maintain a healthy riparian vegetation condition.

4. **Maintenance of a landscape mosaic:** Land managers should understand that it is not sufficient for bat conservation to simply draw buffer zones around potential roosts. For instance, the farther a roost is from a foraging area, the greater are the energy demands placed on the bats and (all else being equal) the less suitable the habitat mosaic. The spatial arrangement of foraging and roosting sites, as well as their connectivity with suitable commuting habitat, needs to be carefully considered (Pierson 1998, Herder and Jackson 1999). As suggested in the Habitat, Foraging and Area Requirement sections, roosting, watering, and foraging habitat should probably occur within roughly 1 to 4 km of each other in a configuration that minimizes total time commuting between them. Further, the scale of habitat patches should be such that all these features can coexist within roughly 40 hectares. Ideal sites have roost structures (e.g., maternity caves, warm cliffs, moderately decayed snags) immediately proximate to water bodies (e.g., streams, lakes, beaver ponds) in a heterogeneous mix of native vegetation communities (e.g., ponderosa pine or Douglas fir-intermixed with meadows, pinyon-juniper, and/or sagebrush). The nature of this mix changes geographically, so Region 2 land managers must first get an idea of what good *Myotis thysanodes* habitat consists of in their area by doing bat surveys and evaluating areas of occurrence with the above criteria in

mind. Beginning with areas of known *M. thysanodes* occurrence, land managers can strive to stabilize habitat through a combination of activities that preserve roosts (e.g., gate caves and mines to prevent human disturbance; and manage timber harvest to maintain appropriate structural conditions and snag densities), preserve water bodies (control grazing pressure, maintain natural hydrology), and preserve foraging habitats (minimize pesticide use, conduct logging to promote heterogeneous native vegetation communities).

5. **Elimination of exposure to toxic chemicals:** Where bats may be exposed to toxic surface impoundments, such as cyanide ponds from mining activities, those ponds should be netted or otherwise restricted to prevent bats from drinking from them. Colorado requires this to be done when ponds contain more than 40 parts per million of cyanide (Ellison et al. 2004). Further, wetlands with sediment containing compounds that might be bioaccumulated by higher trophic levels (e.g., organochlorines such as DDT and DDE) should be remediated per guidelines established by the Environmental Protection Agency (Lee and Jones-Lee 2002, <http://www.epa.gov/superfund/resources/sediment/guidance.htm>). Until such remediation is successful, bats should be kept from using areas, and emergent aquatic invertebrates in these ponds should be controlled to prevent bat consumption of chemicals that have bioaccumulated in insect tissues. Pesticide use (for any reason) should be minimized and targeted to reduce spray block size, non-target insect mortality, and the potential for spray drift (Ellison et al. 2004). Any intensive spray area should be searched for roosts prior to spraying and a 2-mile, no-spray buffer should be left around roost sites (Ellison et al. 2004) to minimize the potential of direct poisoning of bats. Further, aerial application should be timed so that it does not directly contaminate foraging bats (i.e., not during the early evening, night, or before sunrise).

Survey, inventory, and monitoring

Detailed accounts of bat monitoring techniques are presented in several sources (e.g., Altenbach et al.

2002, Kunz 1988, Ministry of Environment, Lands, and Parks 1998, O'Farrell and Gannon 1999, O'Shea and Bogen 2000). Many land managers would prefer to monitor general habitat conditions rather than to conduct actual bat surveys, because habitat monitoring is often easier and cheaper to conduct. However, given that bats interact with their environment in complex ways (see above sections on Habitat, Activity and movement patterns, Food habits, and Community ecology), and their population response to general habitat conditions is therefore poorly understood, we do not recommend monitoring habitat components as a surrogate for direct surveys. The following is a list of some key ideas and pitfalls that managers should consider when planning bat surveys, but it is not a complete accounting of how to establish such a program.

Multiple sites and site types: Monitoring plans ideally should include both roost structures (hibernacula, night and maternity roosts) and known, persistent foraging and watering habitat (Pierson et al. 1996). Foraging habitat may include non-wetland areas frequented by bats, such as forest edges or travel corridors (e.g., constricted drainages), when such information is available. Altenbach et al. (2002) recommend employing a 100 km grid system to select at least 60 wetland habitat sites throughout the state of Nevada for annual monitoring. These sites should be stratified by the surrounding habitat types and elevation zones, and emphasis should be placed on unique sites (e.g., large complexes, exceptional habitat heterogeneity) and sites with historic bat data where the long term stability of water sources is known.

Multiple visits: For adequate monitoring, sites should be sampled four times in the monitoring year, maintaining consistency in survey dates (and possibly moon phase) over time. Some roosts, although heavily used over time, may not be used at all on a given night (Weller 2000) so visiting a roost or a watering hole one-time is insufficient for accurate survey and monitoring work. Comprehensive monitoring of roost sites would ideally include surveys during at least three periods: pre-maternity (April – May), maternity (June – August), and post maternity (late August – September) (Herren and Luce 1997). As noted earlier, these dates are coarse estimates, and use of specific roosts undoubtedly fluctuates, with the possibility that different portions of the same cave or mine may be used as both summer roosts and winter hibernacula. When monitoring roosts, utmost effort must be made to minimize disturbance to bats (see discussion below and by ASM 1992 and Riddle 1995), so a variety of specific techniques (e.g.,

acoustic monitoring, visual counts, capture techniques) should be considered.

Acoustic monitoring: Bats are secretive, nocturnal, difficult to capture, and hard to visually observe, making standard wildlife monitoring practices less effective. However, since bats use echolocation to navigate, they are constantly “shouting” and researchers can use special equipment to record and analyze these vocalizations. The two most common systems for this purpose are frequency division bat detectors such as ANABAT® (<http://users.lmi.net/corben/anabat.htm#Anabat%20Contents>; <http://www.titley.com.au/tanabat.htm>) and time expansion bat detectors such as those made by Peterson and using Sonobat® software (<http://www.batsound.com/>; <http://www.sonobat.com/>). These systems are not created equal. They both have strengths and weaknesses. Consequently, biologists considering the purchase of acoustic bat detection equipment are advised to consult with bat experts to determine which is best based on the monitoring goals. We encourage interested parties to carefully read pertinent literature to understand the capabilities and shortcomings of acoustic monitoring (e.g., Lance et al. 1996, Hayes 1997, O'Farrell 1997, Ministry of Environment, Lands, and Parks 1998, Barclay 1999, Britzke et al. 1999, Corben and Fellers 2001, Fenton et al. 2001). Due to potential pitfalls (many of which are discussed in the noted citations), acoustic monitoring should not be used as the sole method of inventory or monitoring, but rather it should be strategically employed as part of a plan that involves other methods noted in this section (e.g., mist netting, roost surveys). There are three basic misconceptions about acoustic monitoring that we note here.

- ❖ **Ease of use:** Contrary to perceptions, these systems are not easy to use. It takes substantial experience under the supervision of experts in bat acoustics to be able to effectively deploy these units and, more importantly, to interpret the data obtained. Do not expect to purchase a unit and begin collecting meaningful data after a few days of study. Draw heavily on the experience of local bat experts who have used these systems before.
- ❖ **Species identification:** Although many bats can be identified to species if the recorded echolocation calls are examined by experienced biologists, many more cannot. Further, only good calls, which may be less

than 10 percent of the recorded calls, can be accurately identified. Bat call signatures are not like bird calls, which are meant to proclaim their identity. Rather, they are functional calls used for navigation. Therefore, the call of a given species (or an individual bat) can change dramatically with the structure of the habitat in which they are flying. Further, there are a variety of calls that have different functions and therefore different signatures (e.g., foraging calls, feeding buzzes, commuting calls, social calls). Again, the guidance of an expert is invaluable.

- ❖ **Recording activity levels:** Without visual confirmation of the bats recorded, one cannot assume that more recorded calls means more bat activity. A simple example of this is that by looking at a series of 20 calls, one cannot necessarily determine whether they represent 20 different bats or a single bat flying back and forth 20 times. Thus, one should be extremely cautious about using acoustic techniques to evaluate activity without additional information on the sites.

Capturing bats: Positive identification of bats and analyses of population demographics require that bats be captured and visually examined, so capture is a necessary component of any bat survey project. The intricacies of capturing bats in mist nets and harp traps are many and cannot be completely addressed here. We recommend that biologists wishing to conduct capture activities review some standard texts addressing such issues (Thomas and West 1989, Kunz et al. 1988, Ministry of Environment, Lands and Parks 1998, Carroll et al. 2002) and then consult with their local chapter of the Western Bat Working Group to receive training from experienced bat biologists. That said, we note a few items useful in planning capture activities targeted toward *Myotis thysanodes*.

- ❖ Since *Myotis thysanodes* forage around vegetation, typically in or near forested areas, methods of survey not tied to water bodies may be fruitful if strategically conducted. For example, one might conduct acoustic surveys along forest edges and net openings along those edges where *M. thysanodes* calls were detected with acoustic monitoring equipment. Further, since *M. thysanodes* may forage above normal mist net levels, it

may be beneficial to employ canopy netting techniques (Kunz 1998).

- ❖ Bats are most easily captured around still, open water, from which they drink water while on the wing and around which many species forage due to increased insect abundance. Many other water sources (streams, seeps, vegetated wetlands, etc.) and habitat features (forest edges, riparian corridors, trail systems, etc.) may be used by foraging bats, but without substantial experience, capture success at such sites is generally very low.
- ❖ Capture efforts designed to monitor breeding bat populations should occur roughly between June and August. In one study in arid areas of Arizona, the majority of bats captured in mist nets over water sources was in the month of July, with some in June and August (Cockrum et al. 1996). In other areas, bats are often captured earlier in spring and later in fall, but until migration studies are done for a particular locality, one cannot be certain that these “early” and “late” captures are not migrating individuals. Capture of pregnant or lactating females generally indicates that a given area supports a breeding population, because female bats will not usually show evidence of reproduction during migration.
- ❖ There is potentially huge variation in daily, monthly, and seasonal bat activity. For instance, the same site may be studied on two nights within days of each other, resulting in 24 captures of four species one night and four captures of one species the other (D. Keinath unpublished data). Thus, just because one night’s effort does not yield many bats does not mean that the sight is not important to bats.
- ❖ Capture at a given water source depends as much on the landscape as on the water source itself. For example, in arid areas with few water sources, individual water bodies may draw bats from much farther away than areas with more abundant and dispersed water sources. Thus, a water source of similar structure may yield far more captures in the arid landscape than in the wet landscape, even though the total number of bats in both

areas may be similar. One must consider the surrounding habitat mosaic when selection a location to capture bats.

- ❖ Since bats do not feed continuously throughout the night and often visit several sites over the course of a night, bat activity at a particular locality can vary throughout the night. As a hypothetical example, a bat may drop out of its day roost at dusk, forage at a nearby wetland for an hour, forage along a forest edge en route to a night roost, rest for a few hours in the night roost, leave the

night roost and forage over a stream corridor before making its way back to the day roost. In this case, a mist net placed over the stream would not be able to capture the bat until quite late in the evening.

Exogenous factors – Bat activity may vary with precipitation, temperature, wind, phase of the moon, and cloud cover, so survey efforts must take these factors into account. The effects of each of these factors are uncertain at best, but rough ideas are presented in **Table 7**. This information should be considered when planning survey activities.

Table 7. Potential effects of exogenous factors on activity of free-ranging bats. This information was extracted largely from discussions presented by Ekert (1982), Kunz (1982), and Grindal (1995).

Factor	Suggested Effects	Possible Mechanisms
Cloud cover (Light)	Heavy cloud cover that noticeably darkens the sky can cause early emergence from day roosts.	Light-mediated inhibition of locomotor activity. Predator (owl) avoidance.
Phase and rising of moon (Light)	Activity is generally reduced as the moon becomes fuller and during those periods of the night when the moon is in the sky.	Light-mediated inhibition of locomotor activity. Predator (e.g., owl) avoidance.
Temperature	Decreasing temperature results in decreased bat activity.	Lower temperatures result in increased metabolic demands of activity. Insect activity decreases with decreasing temperature (Grindal 1995).
Precipitation	Activity response varies with intensity of precipitation. Light rain probably has no impact. Heavy rain can prevent flight entirely. Moderate rain can reduce or alter patterns of activity.	Precipitation can interfere with echolocation, flight, and thermoregulation. Precipitation can also decrease insect activity. Effectiveness of mist-nets is decreased with increasing precipitation.
Wind	Activity response varies with strength of wind. Light or moderate wind probably has little impact. Strong or gusty wind can prevent flight entirely.	Wind can interfere with prey capture, flight, and thermoregulation. Wind can also decrease insect activity.
Food supply	Abundant resources can result in reduced foraging time and consequently more strongly bimodal peaks of activity related to peaks in insect abundance that often occur in twilight periods.	Like most animals, bats forage until energy demands are met, and then rest.
Reproductive phase	Pregnant and lactating females often are very active because they have high energy demands. However, pregnant bats can become less active the closer they are to parturition.	Wing loading becomes higher with more advanced pregnancy, thus making foraging more difficult and energy intensive.
Elevation	Given the same habitat types, activity can be greater at lower elevations (Grindal 1995).	Temperature and insect abundance decrease with increasing elevation.

Monitoring roosts: Monitoring of roost sites is critical to effective management of bats. However, a detailed account of how to monitor roosts, and all the statistical sampling attention that entails, is beyond the scope of this assessment. Survey methods have been covered above and in other documents (e.g., Kunz 1998, Ministry of Environment, Lands, and Parks 1998, O’Shea and Bogan 2000), and general monitoring tips can also be derived from ASM (1992), Riddle (1995), Pierson et al. (1996 and 1999), Altenbach et al. (2002), and local bat experts.

In short, the three biggest monitoring problems typically faced by managers are method of surveys, timing of surveys, and minimizing disturbance to roosting bats. Monitoring surveys should be conducted at least bi-annually on nearly the same date and moon phase each year, and since roosts are typically very sensitive to disturbance, such activities must be minimized and conducted using the least intrusive method that will yield appropriate results. A combination of acoustic and night vision emergence counts at roost openings is least invasive, as roosts are not entered and bats are not handled, so colony counts can be made every year. However, they do not often afford accurate species identification or numbers, and therefore should be used after an initial survey has yielded more detailed species-specific counts. A reduced visitation schedule (e.g., every other year or more) should be considered if actually entering the roost is required, and such visitations should follow established guidelines to minimize disturbance to roosting bats (ASM 1992, Riddle 1995). Capture of bats at roost openings is more disruptive and should be done with great care and on a greatly reduced schedule (e.g., no more than on a triennial basis).

It is generally assumed that nursery exit counts of adult females are most reliable two to three weeks prior to parturition. However, unless precise dates of parturition are known this is somewhat risky for *Myotis thysanodes*, as females become highly secretive about one and a half weeks preceding parturition and established roost clusters break up during this period (O’Farrell and Studier 1973). This could result in undercounting if survey visitation occurs during this time period. Exit counts might best be conducted around the time of parturition, and prior to when the juveniles begin to fly.

Captive propagation and reintroduction

No captive propagation or reintroduction is currently underway, nor is such action recommended

at this time. Unless *Myotis thysanodes* populations undergo substantial crashes that threaten imminent extirpation, conservation effort is more fruitfully spent in roost and habitat preservation and restoration.

Information Needs

Relatively little is known about several key aspects of *Myotis thysanodes* biology that are relevant to management of the species. The following is a list of information needs that we deem most important to establishing effective conservation strategies for this species.

1. **Pesticides:** Research the impacts of modern pesticides most likely to affect bats (i.e., those that are most likely to impact their prey and those that they are most likely to come in contact with either via consumption of contaminated prey or direct exposure). Two avenues of research are important. First, determine the toxicological impacts to bats through environmental exposure to such chemicals. The most likely exposure pathways are through direct contact during foraging flights or while roosting and through consumption of insects that contain high concentrations of chemicals. Second, determine how reductions in insect populations resulting from pesticide application affect bat populations indirectly via a reduction in the local prey base.
2. **Management impacts:** Very little monitoring of bat populations has occurred. What has been done was usually short-term, localized, and focused primarily on direct roost disturbances. Therefore, limited good data on the effects of specific habitat management practices on bats exist. For instance, we do not have data on the effects of fire, timber harvest, or forest treatment (e.g., thinning). To effectively conserve *Myotis thysanodes* we need more information on the effects of timber management practices (e.g., clearcut, salvage logging, forest thinning, group selection, individual tree selection, etc.) on known populations. Research seeking to answer these questions would be invaluable to forest managers seeking to conserve bat populations.
3. **Local roosting habits and roost and habitat suitability:** Research needs to

be conducted to find out where *Myotis thysanodes* are roosting in Region, including the structures and microclimates used across Region 2. Once basic roosting areas and conditions are documented, research is needed to clarify the characteristics of existing maternity and hibernation sites so that those characteristics can be maintained and the suitability of currently unused sites can be evaluated. Similarly, more explicit delineation of optimal *M. thysanodes* foraging habitat is needed. This information can be obtained through radio-telemetry and acoustic surveys.

4. **Metapopulation structure:** More information is needed on the metapopulation dynamics of *Myotis thysanodes*, particularly where subspecific issues are concerned. This is important for defining conservation units. Genetic variation studies would prove useful. Although bats are mobile, they are also closely tied to limited roosting and foraging areas, thus limiting potential dispersal. For instance, the relative level of sympatry between the Black Hills subspecies (*M. t. pahasapensis*) and *M. t. thysanodes*, and thus the extent and validity of the subspecies, is largely unknown. Moreover, we do not know if or how long it might take for local populations to be recolonized after extinction events.

5. **Landscape requirements:** In order to conduct effective large-scale planning that promotes the persistence of *Myotis thysanodes*, it is important to gain a better understanding of the species' habitat needs at this scale. This likely begins with metapopulation analyses (see above) to determine current connectivity between local populations and expands to consider those habitat factors that promote such connectivity and how land management activities influence these factors. Further investigation of relationships noted in the Landscape Context section should be part of such research.

6. **Prey relationships:** Bats can be voracious insect predators, and the insects upon which they feed depend on a suite of habitat features that are not well understood. It is likely that habitat alteration by land management agencies can impact insect communities and thereby indirectly impact bat populations despite the fact that no immediate, direct impacts are obvious (e.g., no roosts are destroyed). Better understanding of this linkage would help managers to understand the impacts of their decisions.

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